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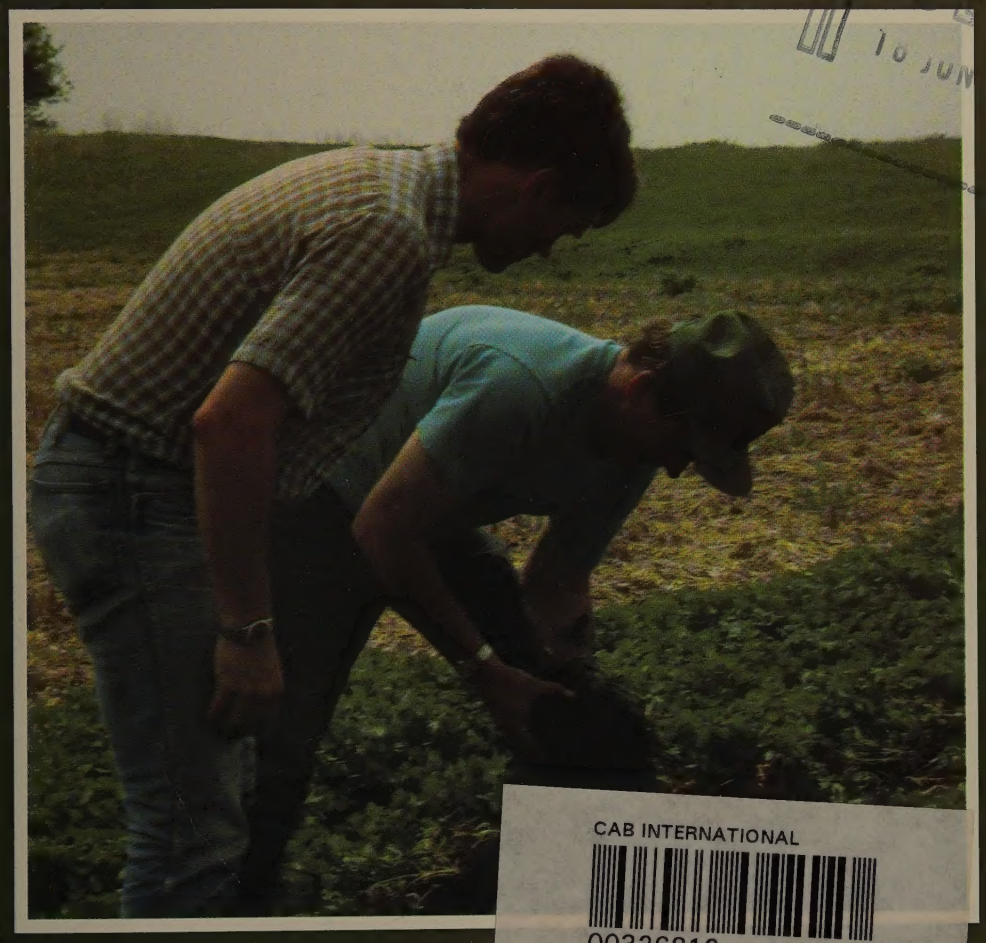

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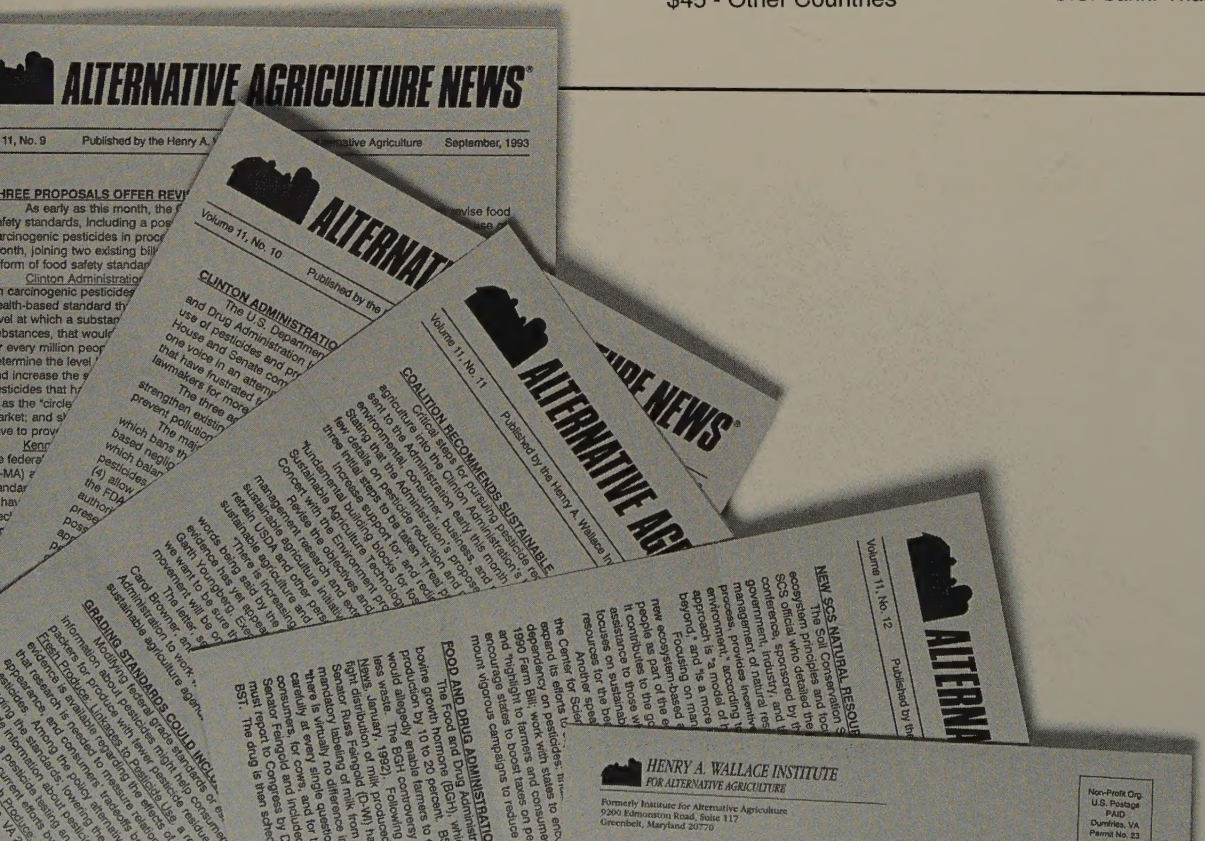

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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

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Cover Photo

Wisconsin farmer Norm Harris and researcher Tom Mulder assess the undercutting of red clover with a chisel plow with sweeps in an on-farm trial. Photograph provided by Ellen Mallory.

Performance, economics, and adoption of cover crops in Wisconsin cash grain rotations: On-farm trials

Ellen B. Mallory, Joshua L. Posner, and Jon O. Baldock

Abstract. *Cover crop performance depends largely on management factors that must be customized to particular farm situations and, therefore, is suited for on-farm research, with farmers involved in both management and evaluation. Cover crop sequences that were successful in a research station study were tested over a variety of soils and management strategies in collaboration with farmers. The two-year cover crop sequences consisted of a short-season crop followed by a cover crop in year one and corn in year two. The cover crops themselves were evaluated by their agronomic and economic performance and their acceptance by farmers. Four cover crop systems (companion-seeded red clover, sequentially seeded hairy vetch, sequentially seeded oat, and fallow) were compared for ground cover, above-ground biomass and above-ground nitrogen yield, subsequent corn grain yield, and N fertilizer replacement value (N-FRV). Cover crops were essential for erosion control following vegetable crops and tillage, but were not necessary following small grains. Companion-seeded red clover produced the most ground cover, yielded up to 133 kg N/ha, and had a higher average N-FRV than sequentially seeded hairy vetch on sandy loam soils, but was not preferred by farmers who harvested small grain straw as well as grain. Sequentially seeded hairy vetch gave excellent cover when no-till seeded, produced more than 125 kg N/ha in half the site-years, and had a higher average N-FRV than companion-seeded red clover on silt loam soils. First-year N-FRV for the legume cover crops averaged 67 kg N/ha over both soil types. The participating farmers indicated that their decisions to adopt cover crops would be based primarily on their need for ground cover, and secondarily on the profitability of using cover crops as an N source. However, when valued solely as an N source for the next year's crop (and not for any potential long-term benefits), cover crops were not an economical alternative to N fertilizer. We suggest focusing future cover crop research and extension efforts on outreach to farmers growing crops that do not provide sufficient ground cover, such as short-season vegetable crops, and optimizing the cover crop system to maximize its erosion control benefits and increase its profitability over N fertilizer.*

Key words: nitrogen fertilizer, fertilizer replacement value, ground cover, on-farm research, Upper Midwest

Cover crops regained attention in the U.S. during the past decade for their potential to address modern agricultural concerns. It is well established that cover crops can be used to reduce erosion (Bruce et al., 1987; Reeves, 1994), improve soil quality (Karlen et al., 1992), suppress weeds (Samson et al., 1990), and in the case of legumes, supply N to subsequent crops (Heichel and Barnes, 1984) and reduce the use of nonrenewable energy (Ess et al., 1994). The challenge is to find cropping systems that can exploit the benefits of cover crops while remaining economically competitive with existing systems.

The resurgence of cover crop work in the U.S. is most evident in the southeast, where the long growing season permits the use of winter legumes in continuous corn (*Zea mays* L.) or sorghum (*Sorghum bicolor* L.). Numerous studies have demonstrated that a leguminous winter cover crop, such as hairy vetch (*Vicia villosa* L. Roth), can provide some, if not all, of the N needed by a subsequent nonlegume (Mitchell and Teel, 1977; Ebelhar et al., 1984; Hargrove, 1986; Smith et al., 1987).

In the northern Corn Belt, the use of cover crops in full-season crops, such as corn, is limited by the shorter growing season. Cover crop practices that have been successful in the southeast, such as seeding after full-season crops, have poor production of biomass and N in the north (Scott et al., 1987; Karlen and Doran, 1991; Bollero and Bullock, 1994). Interseeding cover crops into standing corn at the last cultivation also has been tried, but with similar disappointing results (Scott et al., 1987; Stute and Posner, 1993).

However, there are some suitable cover crop options in the north. These options take advantage of the "open" period of up to three months after the harvest of short-season crops, such as sole-seeded small grains or early canning crops, and involve seeding the cover crop with or after these crops. Table 1 summarizes the research that has been conducted in the northern

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Table 1. Nitrogen content and fertilizer replacement value (N-FRV) of legume cover crops grown in small grain/corn rotations in the northern Corn Belt.

Method of cover crop establishment	Whole plant N content (kg/ha)	N-FRV[1] (kg/ha)	Reference and location
Frost-seeded into winter wheat			
Alfalfa	67	48	Hesterman et al., 1992, Michigan
Red clover	95	127	" " "
Red clover	NA[2]	78	Samson et al., 1991, Ontario
Red clover	NA	56 to 67	Ngalla and Eckert, 1987, N. Ohio
Red clover	108	NA	WICST, 1996a, Wisconsin
Companion-seeded with oats			
Alfalfa	129	90 to 125	Bruulsema and Christie, 1987, Ontario
Red Clover	165	90 to 125	" " "
Alfalfa	85	NA	Hesterman et al., 1992, Michigan
Red clover	37	NA	" " "
Nondormant alfalfa	63	63 to >224[3]	Stute and Posner, 1995, Wisconsin
Dormant alfalfa	55	0[4] to 123	" " "
Red clover	143	95 to >224	" " "
Sweetclover[5]	53	24 to 138	" " "
Hairy vetch	88	40 to >224	" " "
Sequentially seeded after winter wheat or oat harvest			
Red clover	NA	0	Ngalla and Eckert, 1987, N. Ohio
Hairy vetch	NA	112	Samson et al., 1991, Ontario
Nondormant alfalfa	53	88 to 162	Stute and Posner, 1995, Wisconsin
Dormant alfalfa	47	32 to >224	" " "
Red clover	56	29 to 204	" " "
Sweetclover	75	40 to >224	" " "
Hairy vetch	121	74 to >224	" " "

[1] Fertilizer replacement value (N-FRV) is the amount of inorganic N fertilizer needed to produce a subsequent crop yield equal to that produced with a cover crop and no added N (Hesterman, 1988).
[2] Not available.
[3] N-FRV estimate above prediction level with the fertilizer rates used (0-224 kg/ha).
[4] N-FRV estimate below the zero fertilizer control.
[5] *Melilotus officinalis* L. Lam.

Corn Belt with these systems. These studies have shown that legume cover crops can contribute significant amounts of N to a succeeding corn crop. Our work has identified two cover crop systems (companion-seeded red clover [*Trifolium pratense* L.] and sequentially seeded hairy vetch) that produced corn yields equivalent to corn fertilized with up to 224 kg N/ha (Stute and Posner, 1993; Stute and Posner, 1995; Table 1).

While these results are promising, they are based almost entirely on trials on research stations, which often benefit from having the best soils in the region and not having the labor and management constraints faced by farmers. In fact, only two of the studies listed in Table 1 involve on-farm testing, but neither reported an economic evaluation. The latter omission points to another problem; none reported a complete set of data on ground cover, biomass, fertilizer replacement values, and economics. The research also needs to be extended to other short-season crops besides small grains, such as short-season vegetable crops. It is important to compare the most promising cover crop systems in on-farm trials to determine their performance in those settings and to determine their adoption potential as defined by Rogers (1983).

The purpose of our project was to evaluate three cover crop systems comprehensively on working farms. In collaboration with five farmers and one Future Farmers of America group, we compared the two promising cover crop systems that had been identified in earlier station work (companion-seeded red clover and sequentially seeded hairy vetch) to a non-legume cover crop system (sequentially seeded oat [*Avena sativa* L.]) and to a no-cover control (untilled or tilled fallow). We made the comparison both in short-season vegetable crops and in small grains over a range of soil and management conditions. To evaluate the performance of the cover crops we used a full set of criteria: biomass, ground cover, N-FRV, economics, and farmer evaluations.

Materials and Methods

We conducted this cover crop study from 1992 to 1994 at five locations in Dane and Columbia counties in south central Wisconsin. Three farms and one high school demonstration field (Farms A, B, E, and F) completed all three years of the study (two sets of Phase I and II each; see below). Two neighboring farms (Farms C and D) each completed two years (one set

Table 2. Site characteristics and practices that the participating farmers used to manage the cover crops.

Farm	Organic matter (%)	Soil texture	Short-season crop	Seedbed preparation for sequential cover crop seeding[1]	Cover crop kill method[2]
			1992		
A	4.1	Silt loam	Oat	Chisel w/ sweeps Field cultivator	Chisel w/ sweeps
B	2.3	Silt loam	Pea	None (no-till)	Disk
C	1.0	Silt loam	Snapbean	Disk (2x)	Round-up[3]
E	1.0	Sandy loam	W. wheat	None (no-till)	Banvel[4]
F	1.5	Sandy loam	Oat	Disk (2x)	Disk
			1993		
A	3.3	Silt loam	W. wheat	Chisel w/ sweeps Field cultivator	Chisel w/ sweeps
B	3.3	Silt loam	Pea	None (no-till)	Disk
D	3.6	Silt loam	Pea	Disk (2x)	Banvel
E	2.6	Sandy loam	W. wheat	Disk with field cultivator	Banvel
F	1.5	Sandy loam	Oat	Disk (2x)	Disk

[1] Sequentially seeded cover crops were seeded in mid-summer.
[2] Cover crops were killed in the spring following seeding.
[3] *N*-(phosphonomethyl) glycine (1.12 kg a.i./ha)
[4] 3,6-dichloro-2-methoxy benzoic acid (0.56 kg a.i./ha at Farm D and 0.28 kg a.i./ha at Farm E).

of Phase I and II each). The sites were selected according to farmers' interest and soil type, such that a range of soils was represented in the study: three silt loams (Farms A, B and C/D) and two sandy loams (Farms E and F), ranging from 1.0 to 4.1% organic matter in the top 30 cm of soil (Table 2). Weather data are from the centrally situated Arlington National Weather Service Cooperative Station. The participating farmers ranged in age from 32 to 48 years and farmed from 61 to 730 ha.

The short-season crop/cover crop (Phase I) plots were established at Farms A, B, C, E and F in 1992, and again on nearby fields at Farms A, B, D, E and F in 1993. Corn (Phase II) was planted into the cover crop plots in the second year of each trial. The experimental design during the cover crop year at all sites was a randomized complete block with three replications of four treatments: three cover crop systems, and weedy, volunteer vegetation (untilled or tilled fallow). During the corn year, six different rates of N fertilizer (0 to 224 kg N/ha) were applied in a split-plot arrangement to the fallow plots. No N was applied to the cover crop plots, making the experimental design an incomplete factorial of cover crop and N rate. Plot widths were multiples of the farmers' equipment; individual plot sizes ranged from 0.05 to 0.16 ha.

Phase I: Short-season crop/ cover crop

Farmers grew different short-season crops (winter wheat [*Triticum aestivum* L.], oat, pea [*Pisum sativum* L.] or snapbean [*Phaseolus vulgaris* L.]) (Table 2), but all had the same cover crop treatments: companion-seeded medium red clover (cv. 'Arlington', 13 kg/ha), sequentially seeded hairy vetch (common, 34 kg/ha), or sequentially seeded oat (cv. 'Horicon', 72 kg/ha). Exceptions were Farms C and D, which did not include companion-seeded red clover because it interfered with their practice of tilling after pea and snapbean to prevent disease and volunteer problems. All farmers applied the appropriate rhizobium inoculant before seeding and all included a fallow plot as a no-cover comparison treatment. Figure 1 provides an example of the different cover crop sequences in winter wheat. In most cases, fallow plots were untilled after the harvest of the short-season crop. Farms C and D, however, followed their usual practice and tilled all plots after vegetable harvest, including the fallow plots.

On the different farms, "companion-seeded" red clover was either frost-seeded into winter wheat, drilled with oat at seeding, or broadcast immediately following pea seeding. Red clover was frost-seeded between April 3 and 23, and drilled or broadcast between April 13 and May 21. Although strictly speaking not all these seeding methods are companion-seeding, they will be referred to as such in this paper.

We measured short-season crop yields by hand-harvesting three random 0.5-m^2 areas from the companion-seeded red clover and the fallow plots. Peas were weighed fresh, subsamples were tested for tenderness, and yields were adjusted to 100 tenderometer reading. Winter wheat and oat grain and straw were weighed and subsampled to determine moisture content; grain yields were adjusted to 13% moisture.

We planted sequentially seeded cover crops immediately following harvest of the short-season crop between July 21 and August 25. Each farmer decided how to establish the sequentially seeded cover crops. Seedbed preparation ranged from intensive (for example, chisel plow with sweeps once and field cultivator once) to no-till (Table 2). No attempt was made to control weeds, although the seedbed preparation did provide some weed control.

We used the line transect method (Laflen et al., 1981) to determine ground cover immediately following sequential cover crop seeding (week 0) and at 2, 4 and 6 weeks thereafter. A final ground cover measurement was taken following a killing frost (-3° C for 6 hours). At that time, we estimated the above-ground biomass of each treatment by harvesting three random 0.5-m^2 quadrats, 2.5 cm above the soil surface. Samples were separated into cover crop and weed fractions, which included any volunteer crop, then were dried at 60° C for 3 days, weighed, ground to pass a 1-mm screen, and analyzed for N content using a Leco N Determinator (Leco Corp., St. Joseph, Michigan).

Phase II: Corn

Farmers killed the cover crops in early spring with tillage or herbicides (Table 2), then grew corn by their usual practices (except for omitting N fertilizer beyond

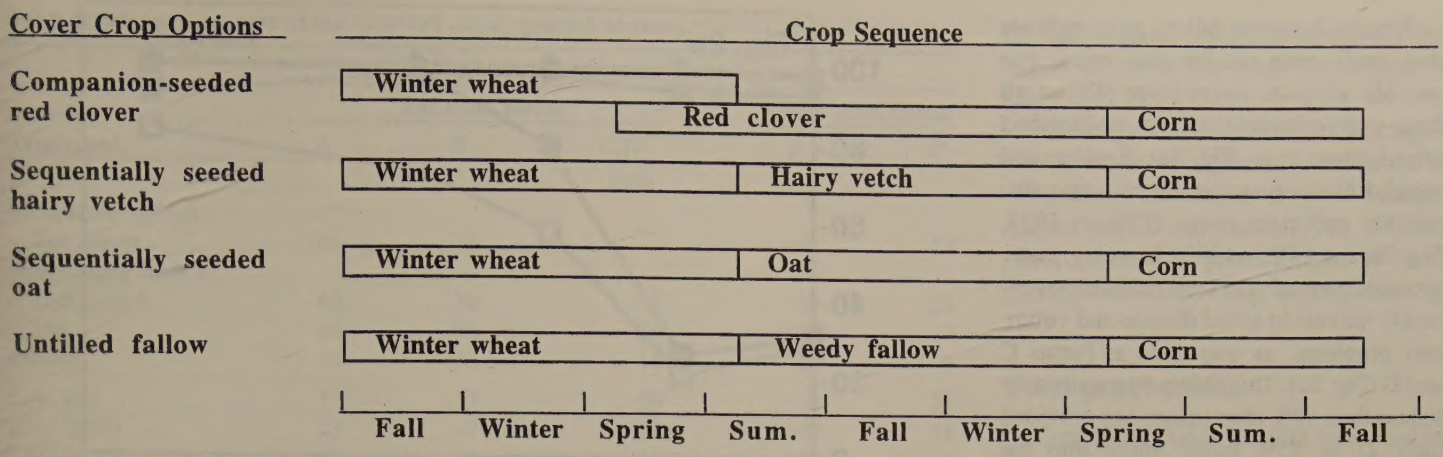

Figure 1. Schematic diagram of the crop sequence for the different cover crop options used in the on-farm trials with winter wheat as the short-season crop. Other short-season crops, such as vegetable processing crops or oat, may be harvested earlier or later than winter wheat.

the 9 to 28 kg N/ha that they applied in starter fertilizer). Corn following the fallow treatment was sidedressed by hand with ammonium nitrate at six N rates (0 to 224 kg/ha). In 1993, N was applied at planting at all sites, but in 1994, N application was delayed at the sandy soil sites until the V6 stage of corn growth (Ritchie et al., 1989). To observe the availability of legume and fertilizer N, we conducted pre-sidedress soil nitrate tests (Fox et al., 1989) to a soil depth of 0.3 m when the corn was in the V6 growth stage. Corn grain yields were determined by hand harvesting 6.1 m of the two center rows of each plot. We did not obtain yield data from Farm D in 1994 because the corn was combine harvested before yield samples were taken.

We evaluated linear and quadratic fits of the corn grain yield response to N fertilizer following the fallow treatment. The best fit equations were then used to estimate the N fertilizer replacement value (N-FRV) of the cover crop treatments. The N-FRV is the amount of inorganic N fertilizer needed to produce a grain yield for corn following fallow equal to the grain yield for corn following a cover crop with no added N (Hesterman, 1988). Starter fertilizer N, applied equally to all treatments at each site, was not included in FRV calculations.

We computed the unit cost of N from the cover crops (cost of using the cover crop divided by its N-FRV) and compared it to that from fertilizer. Total cover crop costs included establishment (seedbed tillage, seed, inoculant, and seeding) and killing (herbicides, spraying, and tillage), and reflected the actual field operations conducted at each farm. Any effects of companion-seeded red clover on short-season crop yields and returns would have been included, but there were none. We estimated material costs by surveying three local agriculture dealers in 1996; machinery costs were based on Minnesota estimates (Lazarus, 1996). The cost of fertilizer N ($0.37/kg N) was based on the current cost of anhydrous ammonia (82% N). We did a sensitivity analysis by changing current cover crop seed prices ($4.32/kg for medium red clover and $2.87/kg for hairy vetch) by ±25% and ±50%.

Data analysis

We analyzed the data for significant main effects and interactions using analysis of variance. The mean square errors across farms (within and independent of soil texture groupings) and between years were found to be heterogeneous, even after the usual variance stabilizing transformations. Therefore, data were not combined over farms nor years. Protected least significant differences (LSDs) are presented at the 0.05 and 0.10 significance levels.

Because of the incomplete factorial design of the experiment, we analyzed the data from the corn phase as two separate groups: cover crop treatments (red clover, hairy vetch, oat, and fallow) and N-rate treatments (0 to 224 kg N/ha applied only to split plots of the fallow main plot). The derived fertilizer replacement values for each year at each site were also subjected to analysis of variance.

Farmer interviews

The farmers participating in this trial were interviewed at their homes between March 21 and March 30, 1994. The farmers had participated in a field tour of each other's plots in September 1992, attended a winter meeting reviewing the 1992 results, and received written updates on the 1993 results. The interviews were informal. They lasted one hour on average, and were audiotaped. We used a series of open-ended questions to initiate discussion of certain topics, followed by more specific questions if needed.

Results and Discussion

Ground cover

The potential for erosion is high during the period when early canning crops and small grains are harvested. Wischmeier and Smith (1978) estimate that one-third of annual erosive rainfall energy occurs between July 1 and August 15. Therefore, if erosion control is a concern, it is important to choose a combination of short-season crop, cover crop, and seeding method that provides adequate cover during this period.

Results from the fallow plots indicate that small grain residue plus weeds can provide adequate cover (over 50% at all farm-year combinations) if undisturbed after harvest (e.g., Fig. 2a). Residue and weeds following a vegetable crop may also provide sufficient cover (77% in 1993, Fig. 2b, and 51% in 1992); however, many growers routinely till their fields after vegetable harvest to avoid disease and volunteer problems, as was done at Farms C and D (Fig. 2c). This reduced ground cover to less than 10% after tillage and provided only 21 to 25% cover going into the winter.

Ground cover for the three cover crop treatments followed different patterns depending on whether the cover crops were established with or without tillage. Companion-seeded red clover always was within a few percent of the highest cover, which began at 53% to 100% and ended the season near or at 100% (Figs. 2a and 2b). However, that system is not always an option after a vegetable crop because of contract restrictions or incompatibility with the weed control program. Alternatively, no-till sequentially seeded hairy vetch and oats did not reduce ground cover below the fallow plots, and by the end of the season hairy vetch provided as much ground cover as companion-seeded red clover (Fig. 2b).

Sequentially seeding hairy vetch or oat after a small grain, with tillage, did reduce the ground cover below that of the companion-seeded and fallow plots. The cover was always 18% or more, however, and it increased rapidly beginning two weeks after seeding (Fig. 2a). Growth curves for sequentially seeded hairy vetch and oat were similar after a vegetable crop and after a small grain. Beginning two weeks after tillage and seeding, the cover crops increased cover more than the fallow and reached 80 to 100% by the end of the season (Fig. 2c). After small grains, cover crops are not necessary to maintain sufficient cover for erosion control. On the other hand, light tillage to seed them is not very detrimental to late-season ground cover and, therefore, to erosion control. After short-season vegetable crops, a cover crop is essential to maintain cover and erosion control if fields are tilled for sanitation.

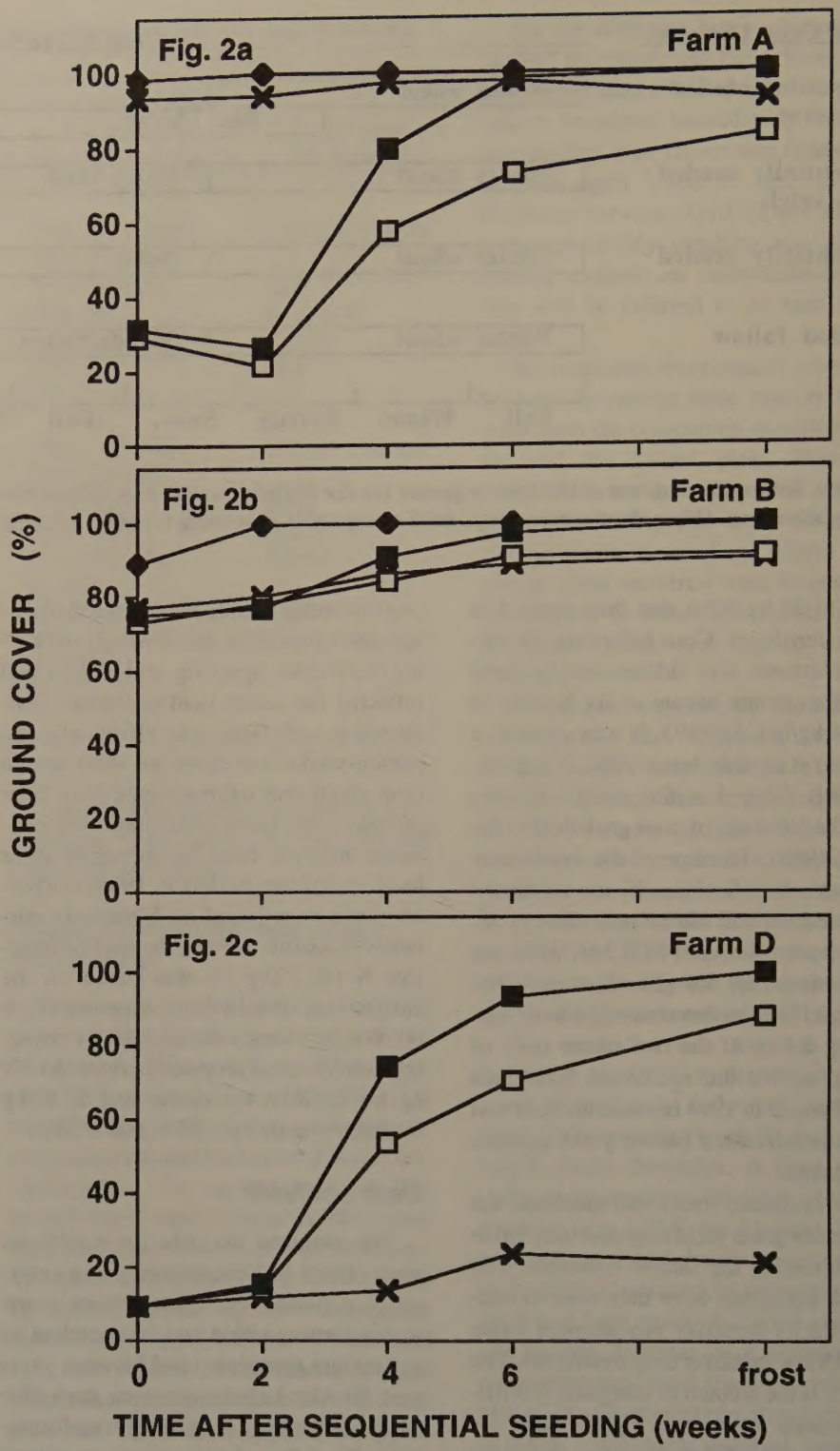

Figure 2. The effect of cover crop treatment on ground cover from sequential cover crop seeding in mid-summer until the first killing frost in the fall at three farms in 1993. Cover crops followed a winter wheat crop at Farm A and pea crops at Farms B and D. Cover crop treatments were: companion-seeded red clover (♦), sequentially seeded hairy vetch (■), sequentially seeded oat (□), and fallow (×). Companion-seeded red clover was seeded in the spring. Sequentially seeded hairy vetch and oat were seeded after wheat or pea harvest, with light tillage, on July 30 and 31 at Farms A and D, respectively. At Farm B, sequential treatments were no-till seeded after pea harvest on July 28.

Table 3. Nitrogen content of the total fall above-ground biomass.[1]

Treatment	Above-ground biomass N (kg/ha)				
	Silt loam farms			Sandy loam farms	
	A	B	C/D[2]	E	F
			1992		
Companion-seeded					
Red clover	104	78	-	41	57
Sequentially seeded					
Hairy vetch	60	138	128	37	24
Oat	60	98	95	16	8
Fallow	43	32	14	20	9
C.V. (%)	17	33	26	38	22
LSD (0.05)	22	47	36	NS[3]	11
LSD (0.10)	17	38	29	17	8
			1993		
Companion-seeded					
Red clover	116	133	-	89	56
Sequentially seeded					
Hairy vetch	184	142	126	68	26
Oat	44	68	82	30	22
Fallow	23	56	17	20	17
C.V. (%)	33	14	17	14	20
LSD (0.05)	60	21	24	14	12
LSD (0.10)	47	17	19	11	10

[1] Includes cover crop, weed, and volunteer small grain biomass.
[2] Data are from Farm C in 1992 and Farm D in 1993.
[3] NS = Not significant.

Cover crop N contributions

Planting a leguminous cover crop significantly increased the N content of the fall above-ground biomass in all but one case (Table 3). Also, above-ground biomass N and above-ground biomass (data not shown) were about twice as high on the silt loam soils as on the sandy loam soils. A possibly confounding effect was that sequentially seeded cover crops were seeded later on the sandy loam soils, since the short-season crops were harvested later on them. Later plantings of legume cover crops in mid-summer generally have lower biomass production (Power and Koerner, 1994). Interestingly, sequentially seeded hairy vetch produced more above-ground N and above-ground biomass than companion-seeded red clover on the silt loam soils, whereas the reverse was true on the sandy loam soils.

To compare our above-ground biomass N results to the whole plant N results obtained previously in our on-station screening study (Stute and Posner, 1995; see Table 1), we assumed that legume tops contain about 70% of the total N accumulated by the plant (Badaruddin and Meyer, 1990). While the N yield of companion-seeded red clover and sequentially seeded hairy vetch grown on the silt loam soils were equivalent to those reported in the previous screening study, the previous study could not warn of the possibility of lower yields on coarser textured soils, since it was conducted on a highly productive silt loam. Of the other work listed in Table 1, only Hesterman et al. (1992) compared cover crop biomass and N yields on soils of different textures; in agreement with our results, they reported that cover crop yields were lower on coarser soils.

As with the legume cover crops, oat stands were much better on the silt loam soils than on the sandy loam soils. In addition, oat N content tended to be higher following leguminous short-season crops (pea and snapbean) than small grains, which is consistent with observations that the N content of grass cover crops depends largely on soil N availability (Reeves, 1994). In many cases, an oat cover crop yielded more N than the vegetation on the fallow plots, which demonstrates the ability of oat to scavenge late-season N (Shipley et al., 1992).

Above-ground biomass N of the leguminous cover crops generally was lower in 1992 than 1993 because of below-average August rainfall that season (1992, 48 mm; 1993, 81 mm; 30-year average, 99 mm) or improved cover crop management in 1993.

Corn grain yields

Corn grain yields in 1993 were low in the cover crop trial (Table 4) and in the rest of Dane and Columbia counties (18% below the five-year average; WDATCP, 1996). This was due to the very cool and wet early spring (April and May had only 70% of average heat units, yet 185% of average rainfall). Kelling et al. (1994) stated that the excessively wet season significantly influenced the N status of Wisconsin soils by increasing denitrification and leaching losses and slowing mineralization from organic sources. In spite of the large biomass N differences among cover crop treatments in 1992 (Table 3), pre-sidedress soil nitrate tests (Fox et al., 1989) conducted the following June showed no significant treatment effects on soil nitrate levels in the cover crop and fertilizer plots (data not shown). This shows that cover crop and fertilizer N were lost through leaching or denitrification, or that N from the cover crop material was slow to mineralize. As a result, cover crop treatment had no significant effect on 1993 corn grain yields at four of the five farms (Table 4).

Cover crop treatment significantly ($p<0.05$) affected corn grain yields in the more normal 1994 season at three of four farms (all farms at $p<0.10$; Table 5). Yields generally were greater following the leguminous cover crops than following oat or fallow, as were soil nitrate levels and grain N concentrations (data not shown), suggesting that N nutrition was the cause of the yield differences.

The correlation between above-ground total biomass N of the cover crop phase and subsequent corn grain yield was insignificant or weak ($r^2<0.45$) in 1993. However, in 1994 this correlation was significant at all farms. Above-ground biomass N yields explained 59, 38, 68 and 80%

Table 4. Summary presentation of 1993 grain yields of corn that followed either cover crops (no additional N) or fallow (fertilized at 0 to 224 kg N/ha)[1].

	1993 Corn Grain Yields (Mg/ha)				
	Silt loam farms			Sandy loam farms	
Treatment	A	B	C	E[2]	F
Companion seeded Red clover	7.8	8.1	-	2.7	6.6
Sequentially seeded Hairy vetch	8.0	8.3	9.0	5.2	5.9
Oat	7.0	6.8	7.8	2.1	3.8
Fallow (no N)	7.5	6.6	7.9	0.8	4.5
C.V. (%)	7.0	13.6	12.7	33.7	24.1
LSD (0.05)	NS[3]	NS	NS	1.8	NS
LSD (0.10)	NS	NS	NS	1.4	NS
Fallow N rate (kg/ha)					
0	7.5	6.6	7.9	0.8	4.5
45	8.5	8.2	9.3	1.2	5.0
90	8.7	8.0	9.5	2.5	7.0
134	9.0	8.0	9.8	4.4	8.0
179	9.2	9.0	9.6	5.0	9.0
224	9.1	8.1	10.6	5.0	8.3
C.V. (%)	3.1	11.3	7.3	24.1	7.4
N rate contrasts					
Linear	**	*	*	**	**
Quadratic	**	NS	NS	NS	**

[1] An equal amount of starter fertilizer N (9-28 kg/ha) was applied to all treatments at each site. Fertilizer N treatments refer to the 0-224 kg/ha applied as sidedress.

[2] Failed weed control practices following no-till planting resulted in abnormally low corn yields at this site in all but the hairy vetch treatment, which benefited from a thick mat of herbicide-killed vetch.

[3] NS = Not significant.

*,** Significant at $p<0.05$ and $p<0.01$, respectively.

of the variation in subsequent corn grain yields at farms A, B, E and F, respectively.

Fertilizer replacement values

N-FRV for the leguminous cover crops in this trial ranged from 15 to 111 kg N/ha (Table 6), and tended to be lower in 1993 than in the more favorable 1994 season. To identify the influences on N-FRV, we ran a factorial analysis (year × soil texture × cover crop system) of the 16 legume N-FRVs in Table 6. The only effect that was significant was soil texture × cover crop system. That interaction resulted from companion-seeded red clover furnishing more N on sandy loam soils than sequentially seeded hairy vetch (83 versus 45 kg N/ha), in contrast to sequentially seeded hairy vetch furnishing more N than companion-seeded red clover on silt loam soils (83 versus 54 kg N/ha). This interaction paralleled the biomass N production discussed above. Because there were only four to five observations in each of those means, the standard errors were large (11.0 to 14.7), so more research is needed to refine these estimates. Our data suggest that on sandy loam soils, companion-seeded red clover is a better option than sequentially seeded hairy vetch. As for the silt loams, our data indicate that there are more options. The ease of companion seeding is attractive. However, if we want clean small grain straw or cannot use a companion legume for other reasons, then sequentially seeding hairy vetch is competitive. Although we could not separate cover crop species from time of planting in this study, the cover crop systems that we compared were selected from a screening study that evaluated many different combinations of legume cover crop and planting time (Stute and Posner, 1995).

The N-FRVs resulting from our on-farm trials were at the low end of the range in N-FRVs from research station studies (Table 1), indicating that the research station studies tend to overestimate the N-FRV, or that farmers' cover crop management should be improved, or both. N-FRV could not be estimated for oat in five of the nine farm-years because yields were lower following oat than following fallow at 0 kg N/ha. Depressed yields following small grains have been observed previously (Blevins et al., 1990; Bollero and Bullock, 1994; Reeves, 1994). Although N content of the oat dry matter in the fall was high in many cases, it appears that mineralization of N from oat tissue was slow or that the yield-depressing factors exceeded the N contribution.

Cost of cover crop N

The average cost of companion-seeded red clover N was $1.30/kg (range $0.66 to $3.88/kg), more than three times the current cost of fertilizer N ($0.37/kg). Sequentially seeded hairy vetch N was even more expensive ($2.25/kg; range $1.04 to $4.72/kg). Seed cost constitutes three-quarters of the total cost of using the cover crops. If cover crop seed prices dropped by 25%, red clover N would still be 2.6 times more expensive than fertilizer N; a 50% drop would bring it down to 1.9 times the cost of fertilizer N.

Cover crop treatments are placed at a disadvantage by two shortcomings of this type of experiment and economic analysis. First, the analysis does not account for long-term benefits of cover crops, such as erosion control and improved soil physical conditions. Although it is difficult to place monetary values on these long-term benefits (Power, 1987), they undoubtedly are valuable in maintaining the future profitability of cropping systems (Faeth et al., 1991). Second, the experiment and results were likely influenced by collecting the data during the transition from a soil fertility strategy based on fertilizers to one relying on legumes. Other studies have shown that corn yields in cover crop systems often are less than in conventional systems during a three- to four-year transition phase, but afterwards are at least as high (Liebhardt et al., 1989; WICST, 1996b). This may occur because of equilibration of

Table 5. Summary presentation of 1994 grain yields of corn that followed either cover crops (no additional N) or fallow (fertilized at 0 to 224 kg N/ha)[1].

	1994 Corn Grain Yields (Mg/ha)				
	Silt loam farms			Sandy loam farms	
Treatment	A	B	D[2]	E	F
Companion seeded					
Red clover	13.8	7.0	-	10.4	8.9
Sequentially seeded					
Hairy vetch	14.2	9.1	-	9.0	6.7
Oat	11.5	6.9	-	6.9	5.5
Fallow (no N)	11.4	4.8	-	6.8	4.9
C.V. (%)	7.3	25.1	-	7.9	18.9
LSD (0.05)	1.8	NS[3]	-	1.3	2.5
LSD (0.10)	1.5	2.4	-	1.0	1.9
Fallow N rate (kg/ha)					
0	11.4	4.8	-	6.8	4.9
45	12.6	6.4	-	10.0	6.4
90	14.3	8.4	-	10.5	9.3
134	14.4	10.3	-	10.9	10.3
179	14.3	10.8	-	11.3	11.0
224	14.5	10.6	-	10.9	11.0
C.V. (%)	5.7	10.7	-	9.5	7.2
N rate contrasts					
Linear	**	**	-	**	**
Quadratic	*	*	-	**	**

[1] An equal amount of starter fertilizer N (9-28 kg/ha) was applied to all treatments at each site. Fertilizer N treatments refer to the 0-224 kg/ha applied as sidedress.
[2] Corn was combine harvested before yield samples were taken.
[3] NS = Not significant.
*,** Significant at $p<0.05$ and $p<0.01$, respectively.

Table 6. Estimates of fertilizer replacement values of the cover crops[1].

	Cover Crop N-FRV (kg N/ha)				
	Silt loam farms			Sandy loam farms	
Treatment	A	B	C/D[2]	E	F
			1993		
Red clover	15	75	-	82	75
Hairy vetch	25	94	55	219[3]	50
Oat	#	#	#	58	#
			1994		
Red clover	79	47	-	87	88
Hairy vetch	111	103	-	43	37
Oat	2	46	-	#	16

[1] FRVs were calculated without accounting for the small amount of starter fertilizer N applied equally to all treatments.
[2] Data are from Farm C in 1993. In 1994 at Farm D, corn was harvested before yield samples were taken.
[3] This FRV is suspected to be artificially high, reflecting the weed suppression effects of a thick mat of hairy vetch more than the vetch's N contribution.
means that N-FRV estimate was below the 0 N fertilizer control.

biological processes in the soil, or because farmers and researchers are learning about the nuances of a new system and adapting that system to their farms.

Farmer interviews

Our purpose in interviewing the farmers participating in the cover crop trial was to understand why they would or would not adopt cover crops. This would help focus future cover crop research and extension efforts.

The leading reason that the farmers considered using cover crops was to control erosion. They said that they are "willing to spend some money to maintain soil productivity" (Farmer A) because "you can't put a price on the soil protection, but you know what can happen if it's bare" (Farmer E). These farmers also said that the N benefits are an important factor in their decision to use cover crops, although secondary to erosion control; some also mentioned the soil improvement benefits.

Cost was mentioned first by all the farmers when asked what concerns would affect their decision to use cover crops. Farmers considered both the direct costs associated with cover crops (seed, seeding, and killing) and the indirect costs (any negative effects the cover crops might have on main crops). For example, although companion-seeded red clover was inexpensive, provided excellent ground cover, and contributed N, the wheat farmers said that they would not use it because it can interfere with straw harvest. Given recent wheat market trends, they can earn as much from clean straw as from grain (Oplinger et al., 1992).

Some of the farmers expressed concern that overwintering covers could harm the following corn crop by depleting spring soil water or becoming a weed (additional indirect costs). However, most said that both of these potential problems could be addressed with proper management.

The farmers were not concerned with the possible machinery changes and labor demand associated with cover crops. One mentioned that he wouldn't sequentially seed cover crops unless he had a no-till drill. In general, however, cash grain farmers already have the machinery needed to plant and manage cover crops. Also, the work associated with cover crops occurs

during slow times for cash grain farmers, i.e., early spring before corn planting, and mid-summer.

Adoption potential of the cover crop system

Rogers (1983) outlined five fundamental characteristics of new technologies that influence their chance of being accepted and used by farmers: 1) compatibility: how consistent a new technology is with the current practices, needs and values of farmers; 2) complexity: the degree to which farmers perceive a practice to be difficult to understand and use; 3) trialability: how easy it is for farmers to experiment with the innovation; 4) observability: the degree to which farmers can see the outcome of a technology; and 5) relative advantage: the degree to which farmers perceive an innovation as better than their current practice. As a new or revisited practice for farmers, cover crops are relatively simple and testable. The farmers in this trial had no difficulty understanding the cover crop systems, recognizing their potential benefits, and trying them out on a small scale. In most cases, cover crops were compatible with the farmers existing systems. No changes in crop rotation or machinery were required, nor was there additional work during peak labor periods. The only case where a cover crop was incompatible was the companion-seeded red clover in winter wheat. Cover crops might also be considered observable, since their effects on ground cover and on cash crop yields can be easily noted by the farmers and their neighbors. However, the long-term benefits of cover crops require many seasons of observation.

The characteristic that will decide the adoption fate of cover crops is their relative advantage, as perceived and realized by farmers. Farmers weigh the possible benefits (erosion control, N production, soil improvement) and the possible drawbacks (cost, soil and water problems, weeds, effect on cash crops) and compare the balance to their current practices. All the farmers we interviewed agreed that the relative advantage of cover crops was high if their current practices left the ground in need of cover. However, when high residue conditions exist, the relative advantage of cover crops was not certain and depended on the benefits and drawbacks recognized by each farmer.

Conclusions

This study is different from previous cover crop work (Table 1) not only because it was conducted on working farms with a variety of soils and management strategies, but also because it takes a comprehensive approach to evaluating cover crop systems by examining their agronomic and economic performance and adoption potential. In this study we found the following:

- The earlier the short-season crop was harvested and the earlier the cover crop was established, the better the cover crop performed.
- To maintain ground cover and erosion control, cover crops are not necessary after small grains, but are necessary after a short-season vegetable crop with tillage for sanitation.
- Companion-seeded red clover contributed the most N to the succeeding corn crop on sandy loam soils, but sequentially seeded hairy vetch contributed the most N on silt loam soils. In both cases, the N-FRV was about 80 kg N/ha.
- The price of N fertilizer would have to more than triple (to $1.30/kg N) for the cover crops in these trials to be as profitable as commercial N fertilizer.
- The cover crop systems in these trials were readily adoptable according to Rogers' (1983) criteria if farmers perceive a relative advantage to them. The farmers participating in the trials indicated that their decision to adopt cover crops would be based first on the need for erosion control and second on the profitability of using cover crops as a source of N. Their main concern in using cover crops was the cost.

Based on these results, we suggest that future cover crop efforts in the northern Corn Belt focus on the following: outreach to farmers who grow crops that do not provide sufficient ground cover, such as vegetable crops; on-farm research to maximize ground cover after cover crop seeding and to maximize and obtain better estimates of the N-FRV of legume cover crops; involvement of farmers in these efforts; and evaluation of these efforts through open-ended, adoption interviews with farmers.

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Reduced chemical input cropping systems in the Southeastern United States: III. Economic analysis

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Abstract. *This study evaluated the profitability of several cropping systems during a 10-year period of an experiment comparing rotations and levels of purchased inputs. Continuous corn or sorghum, corn/wheat-soybean (2-year), and corn/wheat-soybean/corn/clover hay (4-year) were managed with recommended fertilizer and pesticide rates and no-till planting (C) or with N from legumes, conventional tillage, and cultivation for weed control (L). Medium input management (M: medium rate of N and banded herbicides) was included during years 5 through 10. Generally, corn was the least profitable crop, regardless of input level or type of rotation. Rotating crops improved profit more than did adding inputs to continuous corn. With L, average annual profit was: continuous corn, -$64/ha; 2-year rotation, $135/ha; and 4-year rotation, $158/ha. With C, the 2-year rotation increased profit to $165/ha from -$119/ha with continuous corn. The increased profit with rotations was due to greater profits from wheat, soybean, and hay offsetting low or negative profit from corn. Sorghum (grown only in monoculture) was more profitable with L ($34/ha) than with C (-$20/ha). During the 6 years when all input levels were compared, the order of average profit was M>L>C with continuous corn. Generally, profit was not increased by M compared with L in the 2-and 4-year rotations. With L, the cost of weed control was 20% of that for C with corn and 44% with soybean. Cost of N from fertilizer was $0.66/kg, but cost of N from crimson clover (seed and planting costs) averaged $0.92/kg when clover was drilled, $1.27/kg when aerially seeded, and $0.16/kg when naturally reseeded.*

Key words: banded herbicides, green manure, corn, wheat, soybean, clover, no-till, conventional tillage, N fertilizer, rotations

Introduction

A desire to reduce chemical inputs arises from increased concerns that some "conventional" agricultural practices degrade human health or the environment (Council for Agricultural Science and Technology, 1988; Madden, 1988). Agricultural chemicals, especially nitrogen and pesticides, have been linked to surface and ground water contamination, air pollution, and residues on food (General Accounting Office, 1990; U.S. Environmental Protection Agency, 1990; Kellogg et al., 1992). Alternative systems, sometimes called sustainable, reduced input, or low input, have been proposed to eliminate or mitigate the negative impacts of conventional agriculture. These alternatives are based on broad, generalized concepts such as using cultivation, biological controls, pest scouting and management, legumes, winter cover crops, rotations, and organic N instead of chemicals to control pests and to fertilize crops (Cooperative State Research Service, 1991). However, little is known about the complex relationships among agricultural practices, profits, and the environment (General Accounting Office, 1990; Schaller, 1993).

The shortage of information stems from the difficulty in conducting systems research and generalizing such results to benefit farmers whose farming conditions differ from those where the research was conducted. The General Accounting Office (1990, p. 36) concluded that studies "on the economic performance of alternative agriculture ... are few, methodologically limited, and enterprise-specific." They could not conclude, based on the literature available, that sustainable systems were either more or less profitable than conventional systems, but did conclude that farmers felt the systems were less profitable and they "will naturally be reluctant to change existing production practices without convincing information regarding profitability."

One long-term study has been underway in North Carolina since 1985 (King and Buchanan, 1993; King 1994). It compares continuously cropped systems with rotations and evaluates current practices and reduced-input strategies. This article reports the profitability of the cropping systems and input strategies for the first 10 years of the study.

Methods

The experimental procedures were presented in detail in previous articles (King

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Use of trade names does not imply endorsement by the North Carolina Agricultural Research Service, nor criticism of similar products not mentioned.

and Buchanan, 1993; King, 1994). In 1985 an experiment was initiated in the Piedmont of North Carolina to determine the agronomic feasibility of substituting legumes and mechanical weed control for fertilizer N and pesticides. Four crop rotations were established (Table 1) and initially managed with two levels of chemical inputs: current management practices (C) = no-till planting with recommended rates of fertilizer N and herbicides; low-input management (L) = conventional tillage, use of green manures as a N source, and cultivation for weed control. During the first few years of the experiment, yields with L were lower than with C, so in 1990 medium-input management (M) treatments were added, These involved herbicide on wheat (*Triticum aestivum*), banded herbicides on corn (*Zea mays*) and soybeans (*Glycine max*), and moderate rates of N (M1, M2, M4 in Table 1). Herbicide rates for these M treatments are shown in Table 2. During the planning stage of the experiment, an organic farmer suggested we include a treatment receiving fertilizer but no pesticides, so treatment L1N was included: fertilizer N applied after chisel plowing and disking, with cultivation for weed control.

With C, the amount and kind of herbicide used (Table 3) varied annually because of changes in weed type and population. Also, new herbicides were used as they became available (e.g., the post-emergence herbicide nicosulfuron to control johnsongrass [*Sorghum halepense*] in corn). Because of a potential problem with corn rootworm (*Diabrotica undecimpunctata howardi*), carbofuran (Furadan) insecticide was placed with corn seed during planting, but it was discontinued after 1990 because of a lack of response to the insecticide. Due to increasing weed problems in L treatments, herbicides were banded on all L corn and soybean treatments beginning in 1990, and diclofob was used on wheat in 1992 and 1993 (Table 2).

Initially, pesticide rates were based on recommendations published annually in the North Carolina Agricultural Chemicals Manuals (1985-1995). However, a review of the experiment after the first four years led to reducing the rates of some herbicides. Rates of alachlor and atrazine were reduced beginning in 1991 (Table 3).

Since weather, crop, and weed conditions were different each year, the frequency of certain field operations varied from year to year (Tables 4 and 5). For example, the number of tillage operations required to prepare the soil adequately for planting was dictated by soil moisture. Also, we switched from a rotary mower to a flail mower because it distributed residue more evenly and improved the effectiveness of residue incorporation with subsequent tillage. This variation in annual field operations resulted in differences in operating costs among years. For example, operating costs for treatment L1 ranged from $204/ha in 1987 to $256/ha in 1989.

A computerized whole-farm budgeting program was used to calculate crop budgets (Hoag et al., 1987). Input data for the program were the practices, amounts of inputs, and prices of inputs and crops (Tables 2, 3, and 6). Farmers typically modify their rotations to take advantage of changing crop prices. However, since the main objective of the study was to determine the long-term productivity of the rotations, we held prices of inputs and crops constant over the study period (Table 6). Operating costs (Table 7) were for machinery (fuel, lubrication, repairs, and labor), materials, and operating interest. Hereafter, "profit" or "profitable" will refer to gross return minus operating cost (sometimes called returns to ownership, overhead, land, and management).

Table 1. Treatments.

Code[1]	Crop Sequence	Fertilizer N (kg/ha) Corn	Wheat	Sorghum	Pesticides[2]
	Current Management[4]				
C1	Continuous corn	140	—	—	yes
C2	Wheat-soybean/corn	105	90	—	yes
C4	Wheat-soybean/corn/red clover[3] hay/corn/ wheat-soybean/corn/red clover hay/ wheat-soybean/corn/fescue[3] & white clover[3] pasture/fescue & white clover pasture	52	45	—	yes
CS	Continuous grain sorghum	—	—	90	yes
	Low-input Management[5]				
L1	Continuous corn	0	—	—	no
L1N	Continuous corn	140	—	—	no
L2	Wheat-soybean/corn	0	0	—	no
L4	Wheat-soybean/corn/red clover hay/corn/ wheat-soybean/corn/red clover hay/ wheat-soybean/corn/fescue & white clover pasture/fescue & white clover pasture	0	0	—	no
LS	Continuous grain sorghum	—	—	0	no
	Medium-input Management[6]				
M1	Continuous corn	45	—	—	banded
M2	Wheat-soybean/corn	45	45	—	banded
M4	Wheat-soybean/corn/red clover hay/corn/ wheat-soybean/corn/red clover hay/ wheat-soybean/corn/fescue & white clover pasture/fescue & white clover pasture	45	45	—	banded

[1] Treatment codes were changed from previous articles in this series (King and Buchanan, 1993, and King, 1994) to improve clarity in this article. To compare treatments with those in previous articles use the following equivalences: C1=C1d, C2=C2d, C4=C4b, CS=CS, L1=R1, L1N=R1d, L2=R2, L4=R4, LS=RS, M1=R1N, M2=R2N, M4=R4N.

[2] See Tables 2 and 3 for exceptions, rates, and times of application.

[3] Red clover (*Trifolium pratense*), fescue (*Festuca arundinacea*), white clover (*Trifolium repens*).

[4] Plots were fallow in the winter after corn and soybean. All crops were planted no-till except CS which was planted after chisel plowing and disking.

[5] Crimson clover was planted after continuous corn, aerially seeded into soybean, and reseeded naturally after sorghum. All crops were planted after chisel plowing and disking.

[6] Crimson clover was planted after continuous corn and aerially seeded into soybean. All crops were planted after chisel plowing and disking.

Table 2. Type and rate of herbicide used with medium-input (M) and low-input (L) management.

	Corn		Wheat		Soybean			
	Nicosulfurorn (Accent)		Diclofob (Hoelon)		Acifluorfen (Blazer)		Sethoxydim (Poast)	
Year	Rate[1] (g/ha)	Treatments	Rate (l/ha)	Treatments	Rate[1] (l/ha)	Treatments	Rate[1] (l/ha)	Treatments
1990	5	L1, M1	—	—	—	—	—	—
1991	6	L1, L2, L4	—	—	—	—	—	—
		M1, M2, M4	—	—	—	—	—	—
1992	6	L1, M1	1	L2, L4 M2, M4	1.2	L2, L4 M2, M4	0.6+0.6	L2, L4 M2, M4
1993	6	L1, L2, L4 M1, M2, M4	1	L2, L4 M2, M4	—	—	—	—
1994	6	L1, M1	—	—	1.2	L2, L4 M2, M4	0.6 M2, M4	L2, L4
1995	6	L1, L2, L4 M1, M2, M4	—	—	—	—	—	—

Pronamide (Kerb) applied at 2.2 kg/ha to M4 in 1991 (red clover)

[1] These herbicides were banded over the row during cultivation. Rate shown is on whole field basis rather than rate in the band.

We consider only the impacts of varying inputs and resulting yields in long term rotations. As mentioned above, expected crop prices would also have a significant impact. However, the number of price options is too great to examine here. For example, considering just three price levels for four crops produces 81 possible profit scenarios. In addition, planting decisions are made before prices are known. Therefore, the way farmers form expectations would also have to be considered. The impact of price expectation on these results is left for future investigations.

The two management strategies—input levels and rotations— are compared in the following discussion. First, within a rotation, we compare profits with C, M (where applicable) and L. Next, within the C and the L input levels, we compare profits of the rotations. Rotation results are based on an across-farm scenario, that is, equal areas of the farm are planted in each crop of the rotation each year. We also considered an annual scenario in which the entire farm is planted to only one crop each year. To keep the experiment to a manageable size, all crops in the rotation were not grown each year in the 4-year, C rotation. Therefore, we could not calculate across-farm profits for this rotation.

For each harvest, profit for each plot was calculated and analyzed by analysis of variance. A 10% level of probability was chosen to identify statistically significant differences among treatments.

Results

Yields

Obviously, profitability is a function of crop yield. Yields for the first 7 years of the experiment were presented in King and Buchanan (1993) and King (1994). Yield ranges and means for the period covered here are shown in Figure 1. Although high yields were obtained with some treatments in some years, mean yields were low, and as will be noted later, sometimes resulted in loss rather than profit. Therefore, in interpreting the results of this study, one must keep in mind the yield levels shown in Figure 1, and not extrapolate our results to higher-yielding situations.

Input levels

The effect of input levels on profitability of continuous corn or sorghum (*Sorghum bicolor*) is shown in Figure 2. With C, sorghum (CS) and no-till corn (C1) yielded positive returns in only three of the first seven years (sorghum treatments were discontinued after the seventh year). However, they were not always profitable at the same time. Corn was profitable only in 1989, 1991, and 1992, when yields were relatively high because of adequate rain, particularly during pollination (King and Buchanan, 1993). In years when rain was inadequate during pollination (early July), rain generally was adequate during the rest of the summer. Therefore, sorghum, which was planted in late June, performed relatively well in years not favorable for corn. C sorghum was profitable in 1988, 1990, and 1992. The loss in 1989 was due to low yield resulting from herbicide injury (King and Buchanan, 1993). Average returns of C sorghum were $49/ha greater than for corn (-$20 vs. -$69). Also, profit with sorghum was less variable (a range of -$157 to $145 for sorghum vs. -$294 to $205 for corn) and the loss in its worst year was less than with corn. Since prices were assumed not to vary, annual variations stemmed from changes in yields and in costs to combat pests.

For sorghum, returns with almost no pesticides or fertilizer (LS) were equal to or higher than with CS (Fig. 2). On average, L was $54/ha more profitable than C (Fig. 3). In corn, L1 was inferior to C1 in two years, superior in five, and equivalent in three. Average profit was $55/ha more with L1 than with C1, but profits were negative (Fig. 3).

The comparison between C and L for continuous systems (C1 vs. L1 for corn, CS vs. LS for sorghum) shows greater average profitability with L (Fig. 3). The

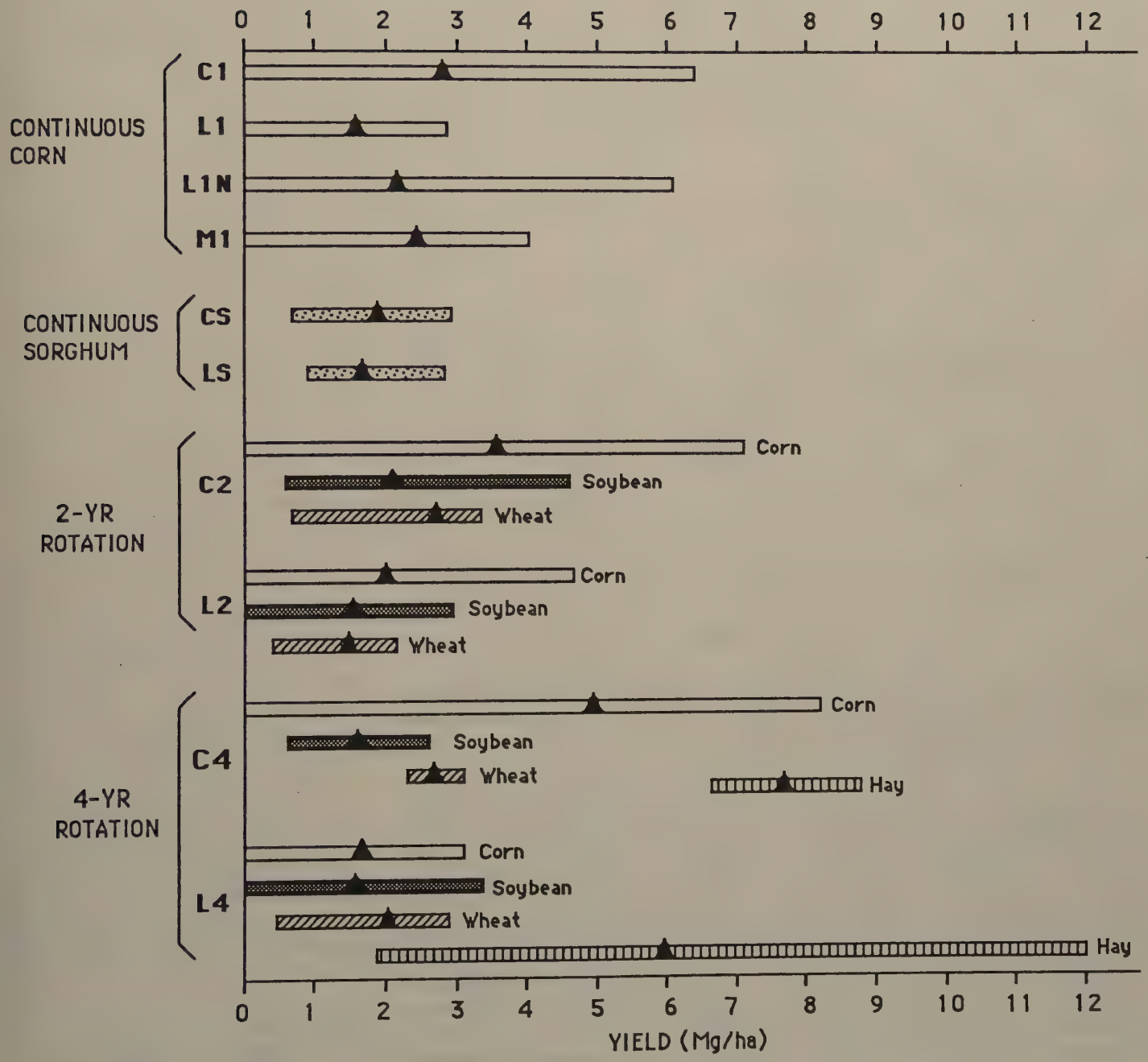

Figure 1. Range and mean (▲) of crop yields during the experimental period.

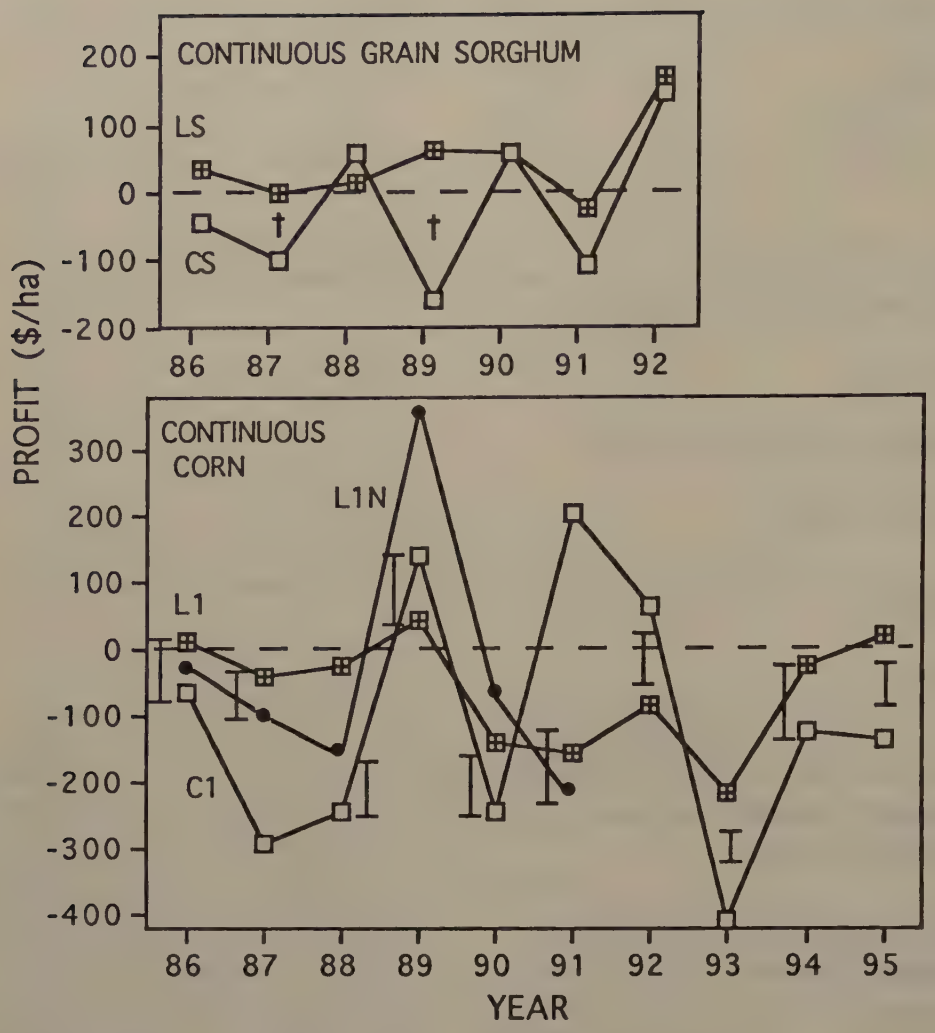

Figure 2. Effect of current (C) and low (L) levels of inputs on profitability of continuous grain sorghum and continuous corn. Significant differences at the 10% level of probability noted with † for sorghum and LSD bars for corn.

L system with no pesticides but with the full fertilizer N rate (L1N) was superior to C1 in three of the six years it was used. However, it was superior to L1 only in 1989 when yields were high because of plentiful rain (Fig. 2).

In the 2-year rotation (across farm) L was superior to C in 1986 and 1995, and C was superior to L in 1991 and 1992 (Fig. 4). Average profit was not significantly affected by management system (Fig. 3). Figure 5 shows the contribution of corn, soybean, and wheat to the total profit presented in Figure 4. Generally, corn was the least profitable crop. Its low profitability was due to its susceptibility to drought during pollination, the high cost of pesticides and N fertilizer with C, and poor weed control and insufficient N supplied by crimson clover (*Trifolium incarnatum*) with L. Soybean was profitable every year except 1993, when the crop failed completely because of drought (Fig. 5). Although soybean yields with C generally were equal to or greater than with L (King and Buchanan, 1993), the lower cost of weed control with L resulted in greater profit from soybean in 1986, 1989, and 1992.

With wheat, C was more profitable than L in every year except 1986 and 1995, when differences were not significant (Fig. 5). Equal profitability in 1986 was an artifact of high residual N fertility from previous management of the site that resulted in equal yields with L and C in 1986. Lack of profit at both input levels in 1991 was due to low yields resulting from heavy ryegrass (*Lolium multiflorum*) infestation. The generally lower profit with L resulted from low yields due to insufficient N.

The only cropping sequence used with C in the 4-year rotation is compared with the same sequence with L in Figure 6. Profit was higher with C in four years and with L in one year. The greater profitability of C vs. L was mainly with corn. In Figure 7, all cropping sequences in the low input 4-year rotation were used to show the contribution of each crop to profit each year. Corn after red clover (*Trifolium pratense*) hay was more profitable than corn after crimson clover because the cost of establishing the red clover was charged to the hay crop. As with the 2-year rotation, soybean and wheat contributed significantly more to profitability than did corn. The hay/pasture treatment was helpful in maintaining profitability in 1990 and 1992, when profit from other crops was low.

The impact of M (supplemental N and use of some herbicides) on profits is shown in Figure 8. In continuous corn, M was superior to L in three of six years; however, M was superior only once in the 2-year rotation and had no significant effect in the 4-year rotation. Although M increased profitability of continuous corn, it did not improve corn profitability in the rotations. For example, in 1991, yield of continuous corn with L was only 900 kg/ha but with M was 3500 kg/ha (290% increase). However, respective yields with L and M were 1660 and 2460 kg/ha (48% increase) for the 2-year rotation and 1450 and 2280 kg/ha (57% increase) for the 4-year rotation. Thus, the large yield increase in continuous corn more than paid for the extra inputs but the smaller yield increases in the rotations barely covered the cost of extra inputs.

Rotations

The first panel in Figure 9 shows the impact of the 2-year, across-farm rotation on profit with C. Rotation raised income over continuous corn every year except 1991. Averaged over the 10-year period, the rotation was profitable but the continuously cropped system was not (Fig. 3). The range of profits also was smaller for rotations. As mentioned previously, since

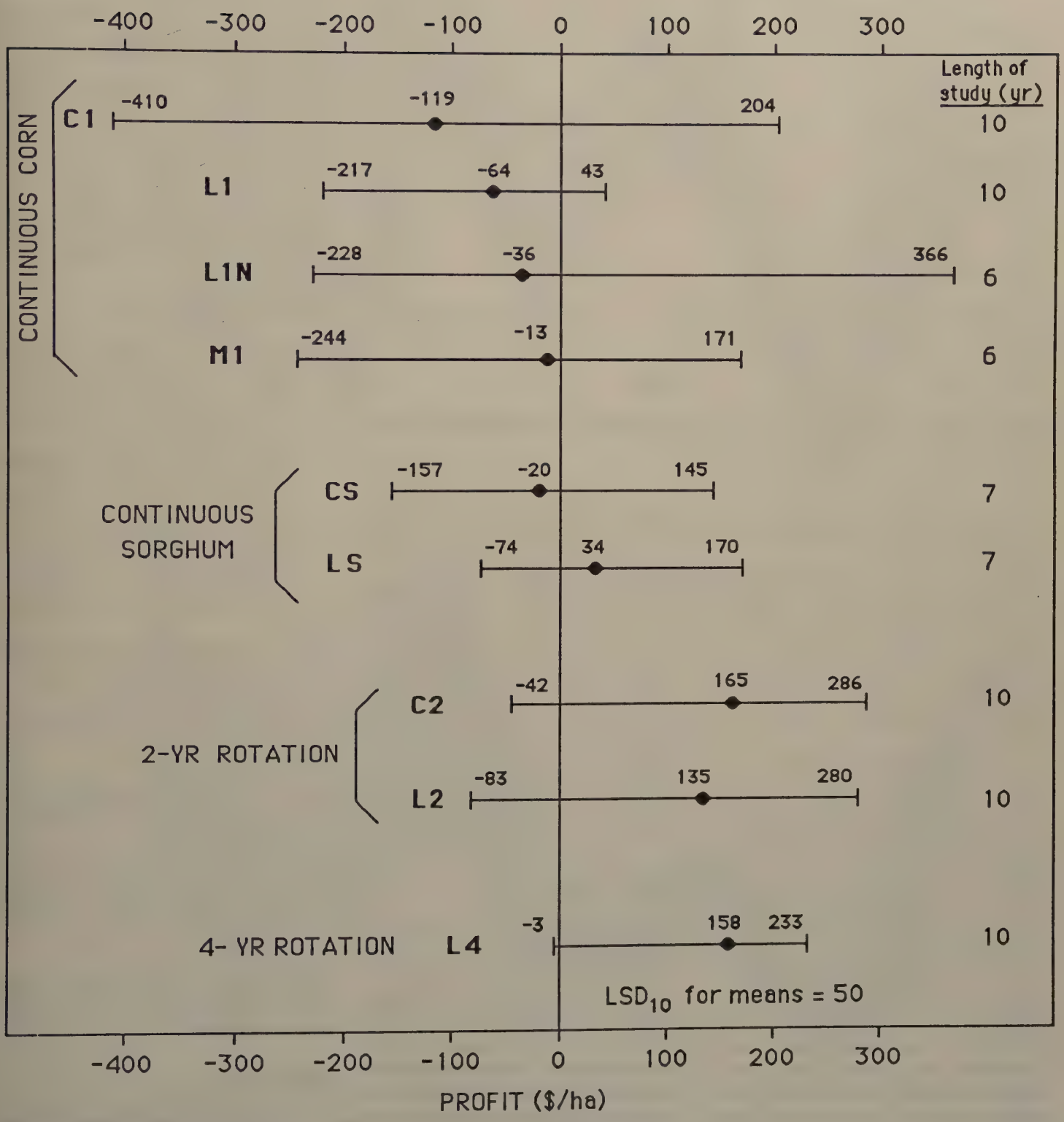

Figure 3. Profit range and mean profit.

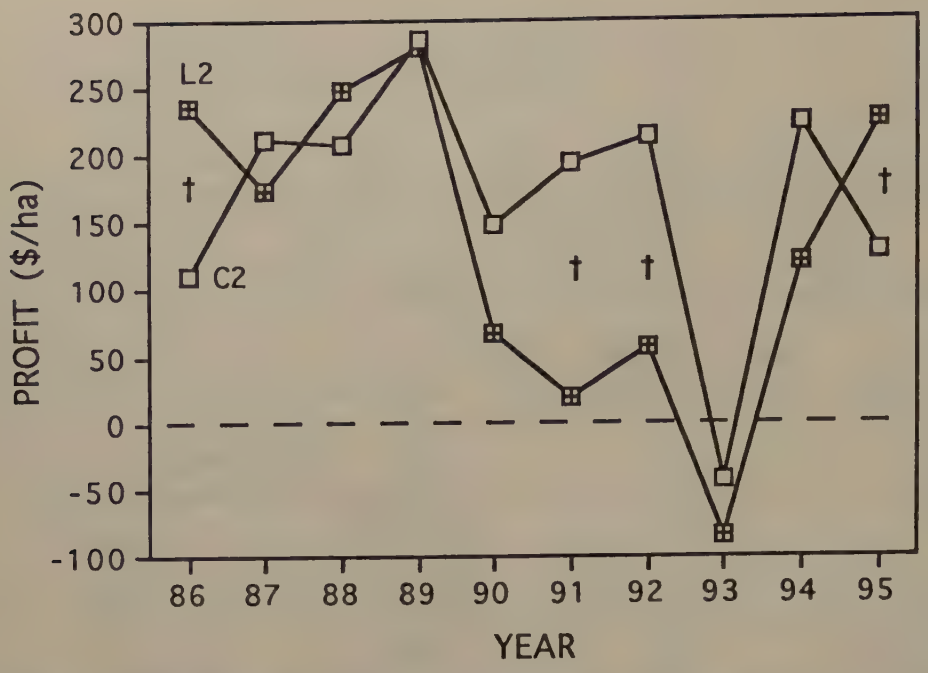

Figure 4. Effect of current (C) and low (L) levels of inputs on profitability in the 2-year rotation. Significant differences noted as in Figure 1.

all crops were not grown each year in the 4-year C treatment, across-farm profits could not be calculated.

The second panel of Figure 9 shows profits by rotation for the L systems. Rotations were consistently more profitable than monoculture corn. The 2- and 4-year rotations were not different during the first four years of the study, but the 4-year rotation was more profitable in three of the next six years.

The greater profitability with rotations was due mainly to including crops more profitable than corn, as shown in Figures 5 and 7. The effect of crops is particularly significant with wheat and soybean, since they are grown in sequence during the same year. The choice of corn for the monoculture crop biased the comparison of monoculture vs. rotation.

Generally, when crops are rotated, fields on a farm are planted to several crops in a given year. This can reduce the risk of low returns due to drought or pest infestations. Also, growing several crops spreads out labor requirements. However, one may prefer to have the entire farm planted to only one crop each year. For example, one might want to concentrate labor into certain periods and leave other periods open for other activities. Table 8 shows how profitability would vary with cropping sequence if the entire farm were planted each year to one crop in the 2-year rotation. With C, corn in even years and wheat/soybeans in odd years were much less profitable than *vice versa.* Comparison of the single crop scenario to the usual multiple crop scenario shows profit could be enhanced or diminished by 36%, depending on which sequence was used. With L, the difference between sequences could increase or decrease profit by 45% compared with multiple crops. Since one cannot predict which sequence will be optimal, risk is reduced by diversifying crops across the farm rather than across years.

Cost of inputs

With corn and soybeans, weed control accounted for the biggest increase in input cost for C compared with L or M. For example, in 1992, weed control in corn cost only 20% as much in L as in C (Fig. 10). For soybeans, weed control in L cost 44% as much as in C. (As noted, herbicides were banded in treatments in 1992.) Since the beginning of this experiment, technology has been developed to use herbicides at reduced rates. For example, when applied in a low volume of water (100 l/ha instead of 400 l/ha, as we used initially), 2.5 l glyphosate/ha is recommended for johnsongrass control. Use of glyphosate at this rate, rather than the 5-l rate, would increase profit by $39/ha. We started using the lower rate in 1995.

Crimson clover was included in the cropping sequence mainly to provide N to the subsequent crop. The cost of providing that N varied with planting method and with the amount of N supplied by the clover (Table 9). The unit cost of N supplied by clover ranged from about 0.15 to 2.5 times the cost of supplying it with fertilizer. The clover also provided organic matter, but we did not attempt to put a monetary value on this contribution.

Conclusions

- Corn was the least profitable crop in the study because of low yield when rain was inadequate during pollination. Soybean was consistently the most profitable crop.
- Rotating crops increased profitability more than did increasing inputs to continuous corn; however, the profits from the two rotations were not significantly different. The rotations were more profitable because they included crops more profitable than corn.
- Medium levels of inputs increased the profitability of continuous corn but had little effect on rotations.
- With L, the cost of weed control was 20% of C for corn and 44% of C for soybean.
- N was cheaper from fertilizer than from crimson clover unless the clover reseeded naturally.
- Crop yields were low, so the results of this study should not be extrapolated to higher-yielding cropping systems.

Acknowledgments. We appreciate the technical assistance of Mark Barnes. Partial funding of this project was supplied by the USDA Low Input Sustainable Agriculture program.

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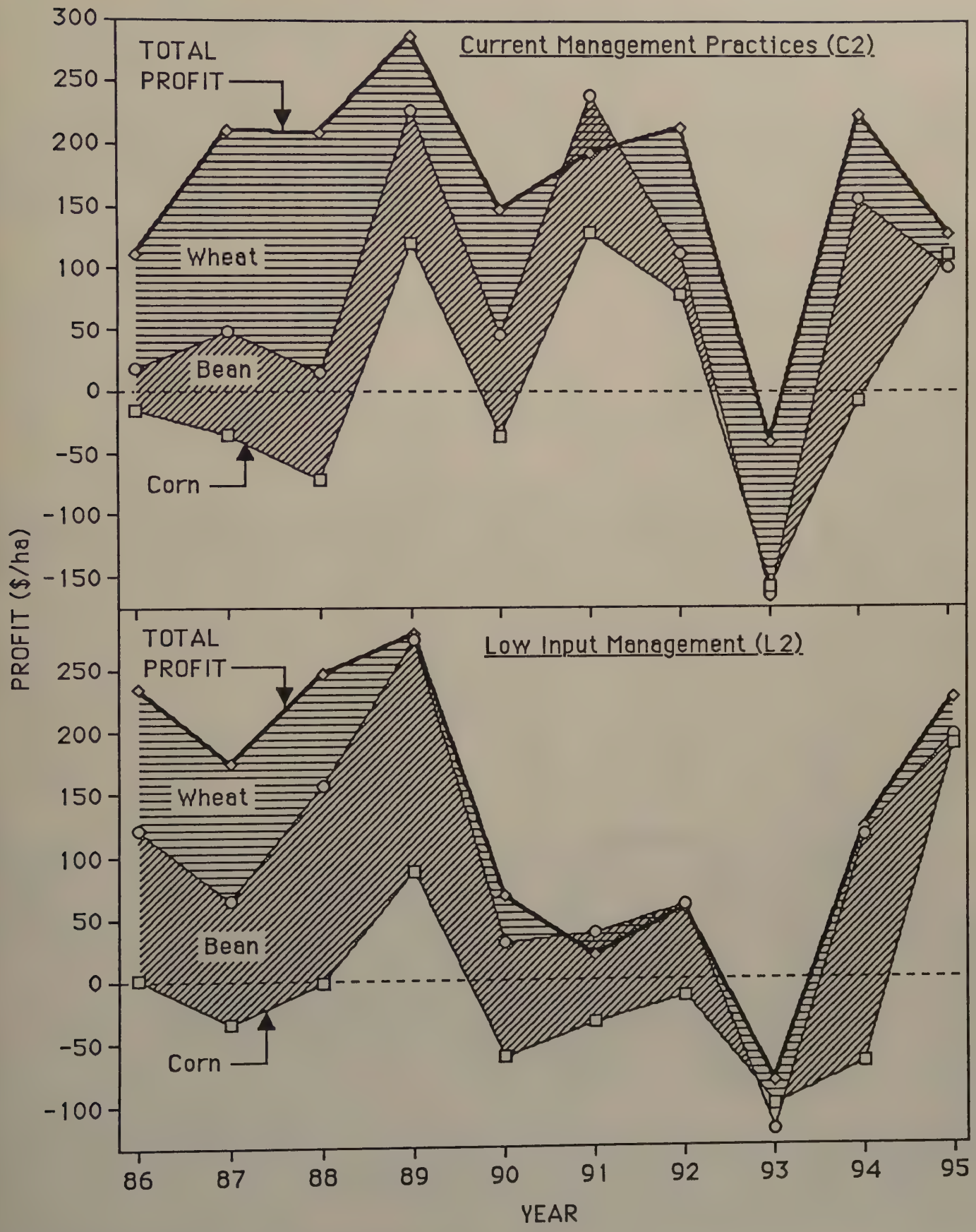

Figure 5. Components of total profit in the 2-year rotation.

Table 3. Type and rate of pesticides used with current management practices (C).

	Corn					
	Carbofuran (Furadan) (kg/ha)	Alachlor (Lasso) (l/ha)	Atrazine (AAtrex) (l/ha)	Glyphosate (Roundup) (l/ha)	Linuron (Lorox) (kg/ha)	Nicosulfuron (Accent) (g/ha)
1986	9	3.1	3.8	5.0	0	0
1987	9	7.5	5.0	3.8	3.4	0
1988	9	7.5	5.0	5.0	0	0
1989	9	7.5	5.0	10.0	0	14
1990	9	7.5	5.0	5.0	0	14
1991	0	5.0	2.5	5.0	0	19
1992	0	5.0	2.5	5.0	0	19
1993	0	5.0	2.5	5.0	0	19
1994	0	5.0	2.5	5.0	0	19
1995	0	5.0	2.5	2.5	0	19

	Soybean					
	Alachlor (Lasso) (l/ha)	Glyphosate (Roundup) (l/ha)	Linuron (Lorox) (kg/ha)	Sethoxydim (Poast) (l/ha)	Paraquat (Gramoxone) (l/ha)	Imazaquin (Scepter) (l/ha)
1986	7.5	7.5	3.4	1.9	0	0
1987	7.5	5.0	3.4	1.9	0	0
1988	7.5	0	3.4	1.9	2.5	0
1989	7.5	7.5	0	1.9	0	0.8
1990	7.5	5.0	0	0[1]	0	0.8
1991	5.0	5.0	0	0[1]	0	0.8
1992	5.0	5.0	0	1.9	0	0.8
1993	5.0	5.0	0	0	0	0.8
1994	5.0	2.5	0	1.9	0	0.8
1995	5.0	2.5	0	1.9	0	0.8

	Grain Sorghum				Wheat		Red Clover
	Alachlor (Lasso) (l/ha)	Atrazine (AAtrex) (L/ha)	Glyphosate (Roundup) (l/ha)	2,4-D (l/ha)	Glyphosate (Roundup) (l/ha)	Diclofob (Hoelon) (l/ha)	Pronamide (Kerb) (kg/ha)
1986	0	5.0	5.0	0	0	0	0
1987	5.0	3.8	3.8	0	5	0	0
1988	5.0	3.8	0	0	0	0	
1989	5.0	3.8	0	0	0	0	
1990[2]	0	0	0	0	0	0	0
1991[2]	0	0	0	0	0	3.2	2.2
1992	5.0	3.8	0	0.2[3]	0	3.2	0
1993	Treatment discontinued				0	0	treatment
1994					0	0	discontinued
1995					0	3.2	—

[1] Use of nicosulfuron on corn in previous year resulted in no johnsongrass in soybean in current year.

[2] In 1990 and 1991, we were unable to get sorghum seed treated to protect the plants from herbicide injury.

[3] 2,4-D banded over row at 0.6 l/ha (0.2 l/ha on whole field basis).

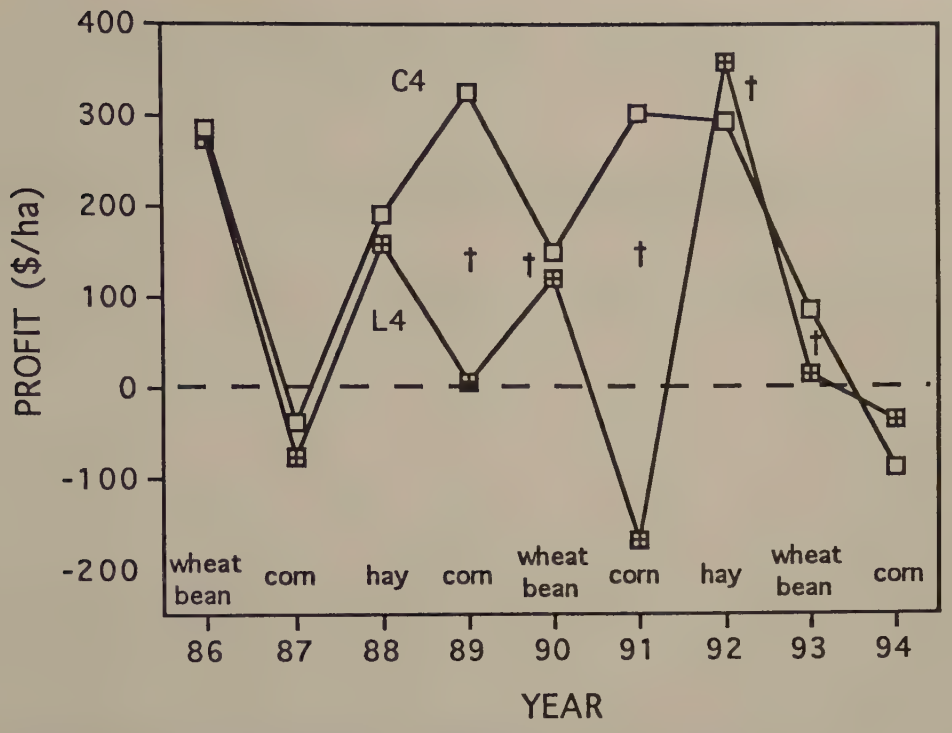

Figure 6. Effect of current (C) and low (L) input levels on profitability of the 4-year rotation. Significant differences noted as in Figure 1.

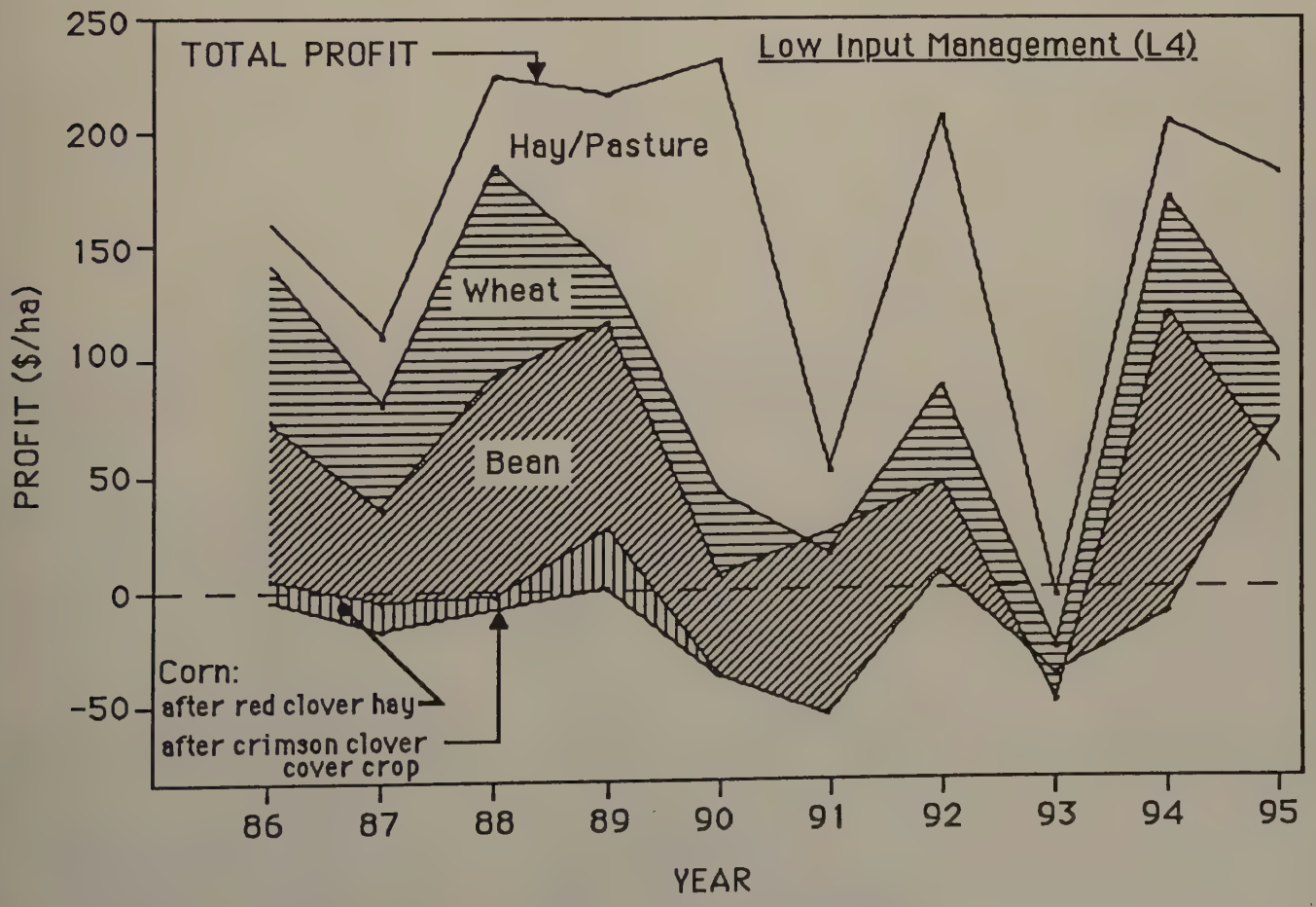

Figure 7. Components of total profit in the 4-year rotation under low input management.

Table 4. Type and number of field operations for row crops in low-input treatments (L).

	Mow		Chisel	Field		Rotary	
	Flail	Rotary	Plow	Cultivate	Disk	Hoe	Cultivate
Corn							
1986	0	1	1	1	4	0	2
1987	0	1	1	0	3	0	2
1988	0	1	1	1	3	0	3
1989	0	1	1	0	2	0	2
1990	0	1	1	0	1	0	2
1991	2	0	2	1	3	1	2
1992	2	0	1	0	1	0	3
1993	2	0	1	0	2	0	2
1994	2	0	1	0	2	0	3
1995	2	0	1	0	1	0	2
Soybean							
1986	0	0	0	1	1	0	2
1987	0	0	0	2	3	0	3
1988	0	0	0	0	2	0	3
1989	0	0	0	1	2	0	2
1990	1	0	0	1	2	0	2
1991	1	0	2	0	2	1	3
1992	0	0	1	0	2	1	3
1993	0	0	1	0	2	0	0
1994	0	0	1	0	1	0	2
1995	1	0	1	0	1	0	2
Wheat							
1986	0	0	0	0	2	0	0
1987	0	0	0	0	1	0	0
1988	0	1	2	0	1	0	0
1989	0	1	0	0	1	0	0
1990	0	1	0	0	0	0	0
1991	0	1	0	1	2	0	0
1992	1	0	0	0	1	0	0
1993	1	0	0	0	0	0	0
1994	1	0	0	0	1	0	0
1995	1	0	0	0	0	0	0
Sorghum							
1986	0	0	0	0	2	0	2
1987	0	1	0	1	3	0	2
1988	0	0	0	0	4	0	1
1989	1	0	0	1	2	0	0
1990	1	0	0	1	3	0	0
1991	1	0	0	2	4	0	0
1992	1	0	1	1	3	0	0

Sorghum discontinued after 1992

Table 5. Type and number of field operations for hay and pasture in low-input (L) treatments.

	Mow		Chisel	Field		
	Flail	Rotary	Plow	Cultivate	Disk	Harvest
Hay						
1986	0	0	0	0	2	5
1987	0	1	0	0	1	3
1988	0	1	2	0	4[1]	3
1989	0	1	1	0	1	2
1990	0	1	0	0	1	3
1991	1	0	0	2	2	4
1992	1	0	1	0	1	3
1993	1	0	1	1	1	2
Hay converted to pasture after 1993						
Pasture						
1994	1	0	0	0	1	0
1995	1	0	2	0	1	0

[1] Because of poor stand, clover was replanted in February.

Table 6. Price of inputs and crops (1986 dollars).

Herbicides ($/l)		**Insecticides** ($/kg)	
Acifluorfen (Blazer)	12.75	Carbofuran (Furadan)	3.12
Alachlor (Lasso)	5.12	Nicosulfuron (Accent)	710.00
Atrazine (AAtrex)	2.35	Pronamide (Kerb)	40.30
Diclofob (Hoelon)	12.88		
Glyphosate (Roundup)	15.73	**Fertilizers/Soil conditioners**	
Imazaquin (Scepter)	43.00	N (30% solution) ($/kg N)	0.60
Linuron (Lorox)	12.48	Lime ($/Mg)	32.45
Paraquat (Gramoxone)	8.81		
Sethoxydim (Poast)	23.35	**Crops** ($/Mg)	
2,4-D (various)	2.40	Soybean	209.48
		Wheat	132.67
		Sorghum	98.44
		Corn	104.34
		Hay[1]	71.66

[1] In addition to red clover, the hay contained a significant amount of ryegrass in the spring and johnsongrass in the summer. Therefore, the price listed is the price of grass hay rather than red clover hay.

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Table 7. Operating costs ($/ha).[1]

Operation	Machinery[2]	Materials	Operating Interest	Total Operating
Mow				
Rotary	11.15	0	1.13	12.28
Flail	16.60	0	1.68	18.25
Chisel plow	5.24	0	0.30	5.53
Field cultivate	7.16	0	0.32	7.48
Disk	5.14	0	0.27	5.41
Broadcast spray	5.53	—[3]	—	—
Plant				
Corn	10.70	39.35	1.83	51.87
Crimson clover				
Drilled	8.82	71.63	8.10	88.57
Aerially seeded[4]	86.25		7.90	94.15
Naturally reseeded	0	0	0	0
Red clover	8.82	76.32	7.81	92.95
Sorghum	10.70	51.72	1.28	65.28
Soybean	10.65	16.75	1.51	28.90
Wheat	8.82	23.66	2.37	34.85
Rotary hoe	1.32	0	0.5	1.37
Cultivate[5]	4.08	—[6]	0.15	4.22
Harvest				
Grains (combine)	17.04	0	0	17.04
Hay				
Sickle mow	9.44	0	0.25	9.68
Rake	9.73	0	0.27	9.98
Bale	16.45	0	0.44	16.89

[1] Operating costs computed using the Budget Planner software (Hoag, et al., 1987) with constant input and output prices given in Table 6.
[2] Includes fuel, lubrication, repairs and labor.
[3] Material cost depends on herbicides used.
[4] Contract price.
[5] The labor portion of this cost depends on tractor speed. Our speed may have been slower than that assumed in this budget program.
[6] Material costs depended on whether herbicide was banded during cultivation.

Table 8. Effect of cropping sequence if whole farm is planted to only one crop in the rotation each year, 2-year rotation.

Management	1986	1987	1995	Profit ($/ha)	Profit (% of across-farm[1])
C	corn	wheat/soybean	wheat/soybean	110	66
	wheat/soybean	corn	corn	225	134
L	corn	wheat/soybean	wheat/soybean	73	55
	wheat/soybean	corn	corn	196	145

[1] Across-farm assumes one-half the farm is in each crop of the 2-year rotation.

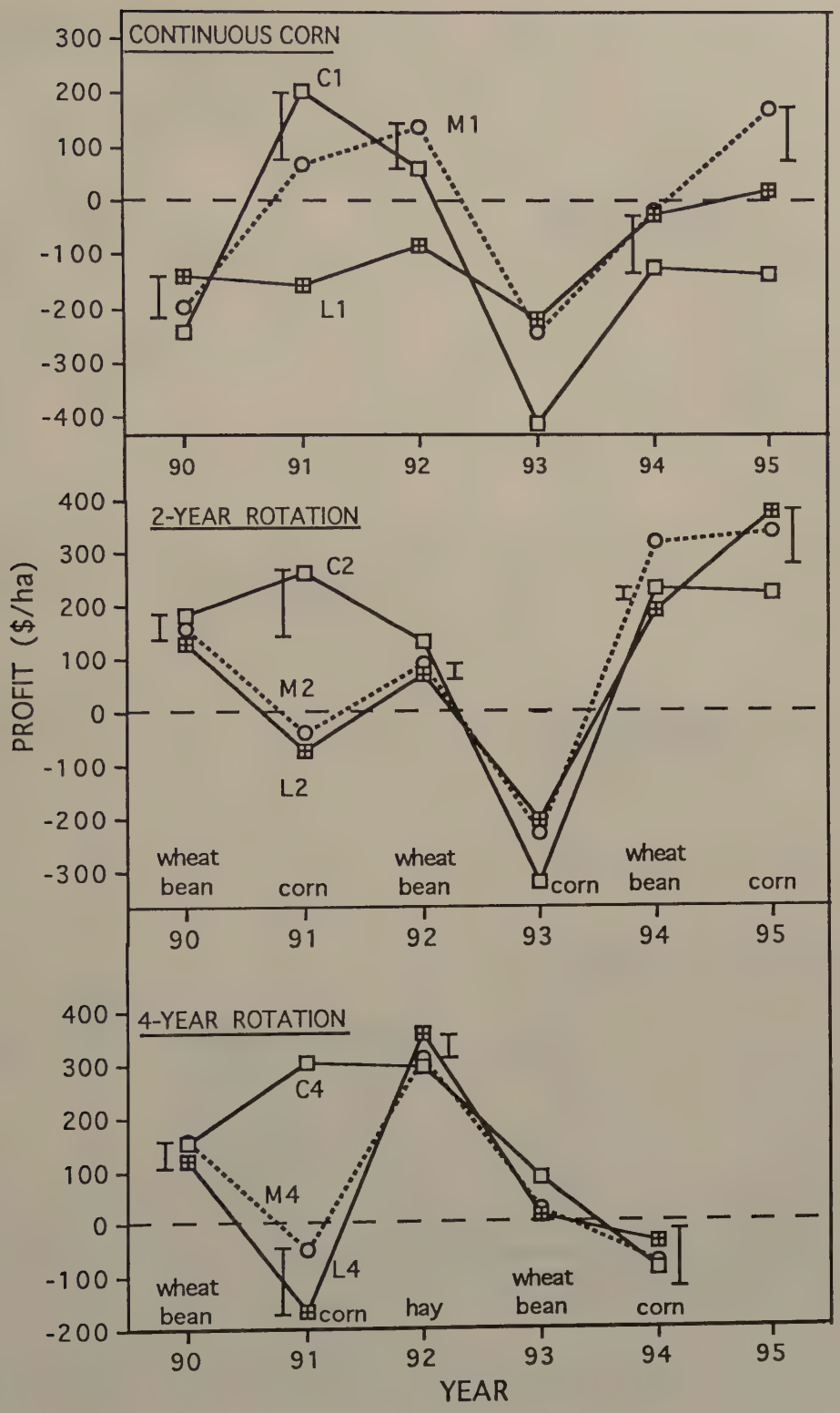

Figure 8. Comparison of low (L), medium (M) and current (C) input levels on profitability of the 1-, 2- and 4- year rotations. Significant differences noted as in Figure 1.

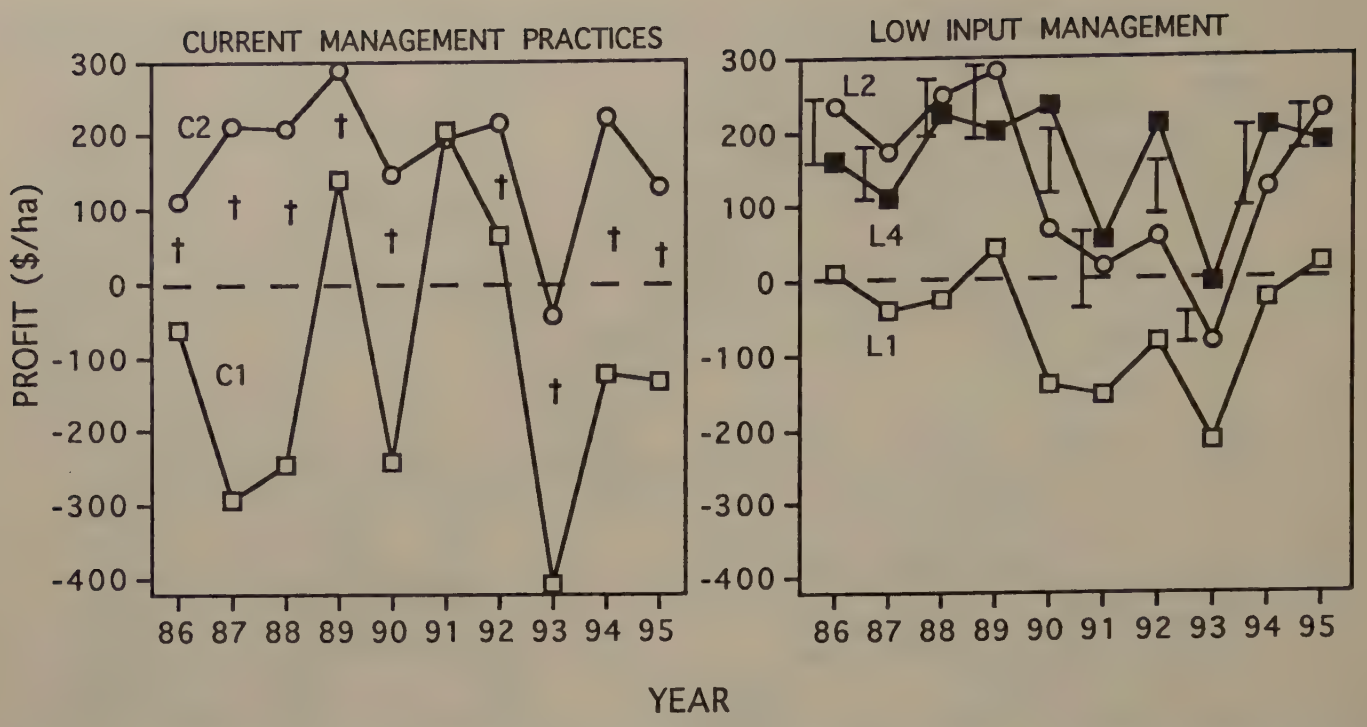

Figure 9. Effect of length of rotation on profitability under current management practices and low management. Significant differences noted as in Figure 1.

Table 9. Comparison of cost of nitrogen sources, 1986-1992.

N source	N rate (kg/ha)	Cost	
		$/ha	$/kg
Fertilizer	140	93.17	0.66
Crimson clover			
drilled	70-150[1]	88.57	1.26-0.59
aerially seeded	56-110[1]	94.15	1.68-0.86
naturally reseeded	56-128[1]	12.65[2]	0.22-0.10

[1] Crozier (1992) found 80% of the total N in crimson clover was mineralized within 8 weeks after being plowed. Thus, these values are 80% of the total N in the clover (King and Buchanan, 1993).

[2] Cost of drilling crimson clover in fall of 1985 prorated over seven sorghum crops.

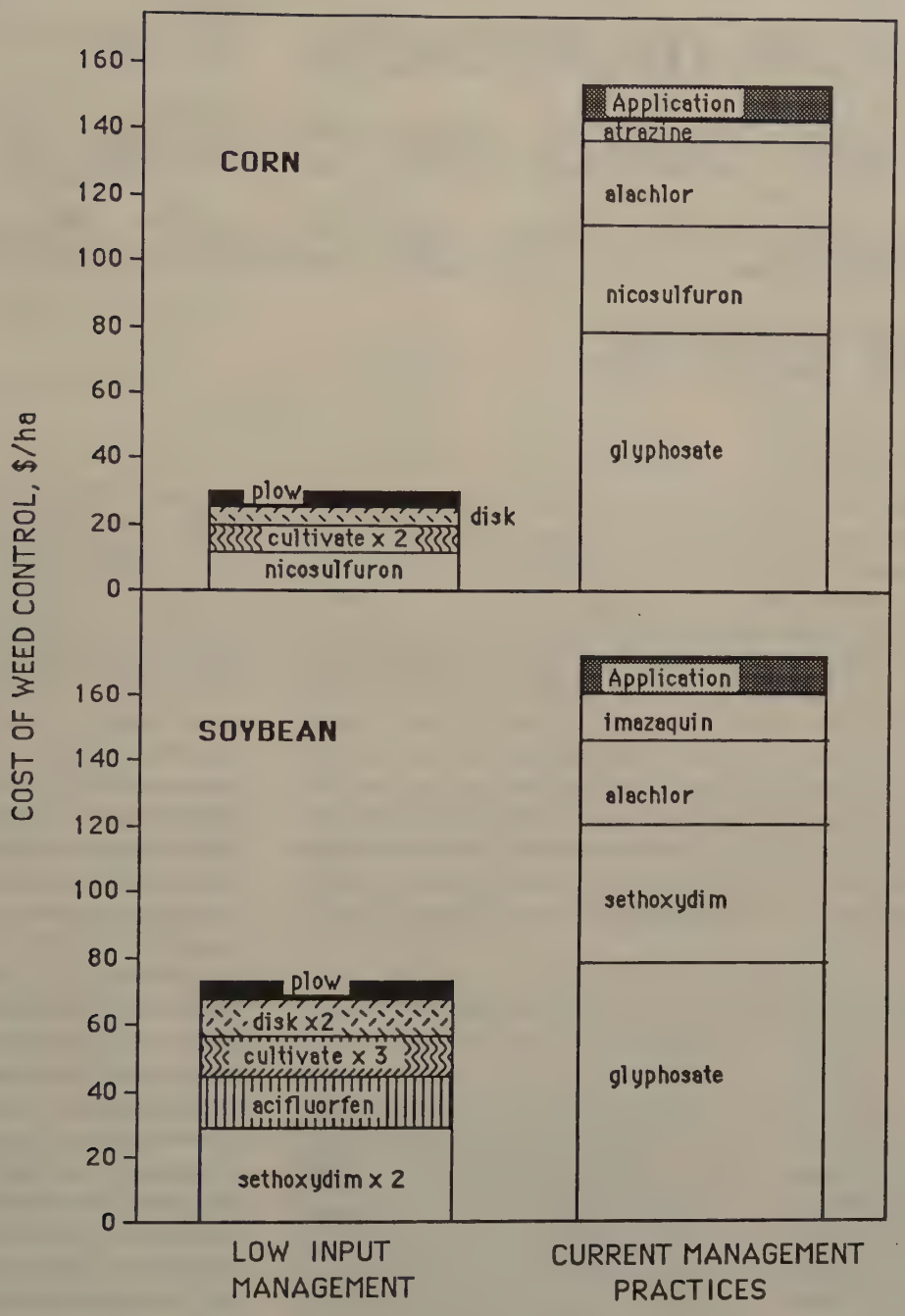

Figure 10. Weed control costs for corn and soybean grown with two levels of management in 1992.

Small-scale, intensive cultivation methods: The effects of deep hand tillage on the productivity of bush beans and red beets.

Ben F. Holt and Ivan K. Smith

Abstract. *This study examined how one aspect of intensive cultivation, double digging by hand (loosening the planting bed to 50 cm deep), contributed to crop productivity and nutrient uptake in bush beans (1994 and 1995) and red beets (1995 only). Comparison beds were prepared with the soil cultivated to 25 cm (single dig) and 6 cm (surface cultivation). Although there were significant differences (1994 beans) between the surface cultivated beds and other cultivation types for leaf mass and chlorophyll content, there were no significant differences in the total mass of beans (whole fruit) produced. There were no significant differences in beet green or root (edible portion) biomass among cultivation methods. Levels of Ca, Mg, and K in the bean fruits and beet roots were not significantly different among cultivation methods. This study demonstrated that deep cultivation significantly alters the soil profile as measured by penetrometer resistance, but that this change does not necessarily alter productivity or nutrient uptake. We suggest that deep hand tillage has little effect on crop productivity in well-watered and moderate to high fertility soils. These results are similar to those found in mechanically subsoiled systems.*

Key words: alternative agriculture, conventional tillage, double digging, no-till, organic amendments, subsoiling

Introduction

Recently, the agricultural techniques advocated in the French intensive/biodynamic method (hereafter "intensive method") have received increased public attention because of the need for highly productive, small-scale, low capital, sustainable methods of agriculture (Tonge, 1987; Stone, 1990; Harrison, 1991; Corbett, 1994). The intensive method is an organic farming/gardening method using several specific cultural practices (see Jeavons, 1991), including double digging (DD) and offset rows. For the purpose of this paper, DD is defined as the loosening of the planting bed to a depth of approximately 50 cm by spade and fork. The placement of seeds or seedlings into offset rows maximizes the use of space in the planting bed. In addition, other typical organic farming practices are followed, such as appropriate irrigation and regular addition of compost and organic fertilizers. Anecdotally, the intensive method is said to give large increases in crop productivity while minimizing resource use, and is, therefore, being recommended as an appropriate food production method for households and small farms in both developed and developing countries (MacFayden, 1985; Tonge, 1987).

The purported higher productivity of the intensive method is attributed largely to the effects of double digging. Crops' responses to deep loosening of the soil profile by various tractor drawn implements (subsoiling) in differing soil conditions have been studied extensively (summarized by Russell, 1956, and Swain, 1975.) Russell examined potatoes, sugar beets, corn, wheat, barley, and oats, and found only small increases (2-5%) in crop yield from subsoiling over a broad range of soil textures. He also found that yields often decreased with subsoiling (see also Marks and Soane, 1987). Swain (1975), however, suggested that in most situations where crops did not respond or where yield decreased after subsoiling, the subsoiling treatment was not properly applied.

Subsoiling is thought to be effective only when the soil profile has a restricting horizon (Swain, 1975; El-Karouri and Gooderham, 1977; Marks and Soane, 1987) and can harm soil structure and subsequent crop yields where porosity already is satisfactory (Swain, 1975; Soane et al., 1987). Also, subsoiling must be performed when the soil is sufficiently dry for maximal subsoil disturbance (Dawkins et al., 1984; Smith, 1995). The proper application of subsoiling has been reported to increase crop yield substantially, with the greatest improvements during years when the water supply limits crop growth (El-Karouri and Gooderham, 1977; Marks and

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Table 1. Soil analysis for samples taken before planting, 1994 and 1995[1].

	1994	1995
Anions (mg/kg)		
NO_3-N(kg/ha)	89.6	89.6
P (plant available)	76.0	112.0
S	11.0	11.0
Cations (mmol/100 g)		
B	0.006	0.009
Ca	1.9	2.7
Ca base saturation (%)	58.5	77.6
Cu	0.003	0.003
Fe	0.08	0.08
Mg	0.27	0.35
Mg base saturation (%)	8.6	10.1
Mn	0.03	0.08
K	0.44	0.59
K base saturation (%)	7.0	8.3
Na	0.15	0.20
Zn	0.006	0.008
Miscellaneous Soil Properties		
Organic matter (%)	2.0	2.7
Cation exchange capacity (mmol/100 g)	6.3	7.1
pH	5.6	6.9

[1] Soil analyses performed by Timberleaf Soil Testing, Albany, Ohio. These values are based on single samples taken from each plot and then combined for an annual soil fertility test.

Soane, 1987; Soane et al., 1987; Barber and Diaz, 1992; Smith, 1995).

During an unusually dry season, Stone (1982) reported productivity increases of 63, 32, 17, and 22% for beans (whole fruit), cabbage, leeks, and red beet (storage root), respectively. Smith (1995) reported increases in cotton yield of 8 and 15% for irrigated and nonirrigated subsoiled fields, respectively. In the Netherlands, subsoiling improved spring wheat yield by 37% on a sandy soil, but other experiments with various crops typically had increases of only 5-6% (Ouwerkerk and Raats, 1986). In Bolivia, the expected yield increases of soybeans during a characteristic wet summer and dry winter are 0 and 56%, respectively (Barber and Diaz, 1992). The yield of wheat drilled into the sandplain soils of Western Australia exhibited a positive and significant linear relationship to depth of tillage (Schmidt and Belford, 1994). Interestingly, the correlation coefficient between wheat yield and tillage depth was higher during a wet year (r^2= 0.87) than a dry year (r^2=0.66) (Schmidt and Belford, 1994). Together, these data suggest that the effects of subsoiling on crop yield are more pronounced in dry years, but that deep tillage cannot overcome excessively low soil moisture. Therefore, the effects of subsoiling are highly variable and depend on soil texture, seasonal rainfall, irrigation, the presence of root-limiting soil horizons, and the type of crop being grown.

Deep cultivation by hand digging, which has received little attention in the scientific literature, does not necessarily have the same effect on yield as mechanical subsoiling. The degree of soil disturbance due to mechanical subsoiling varies with the space between subsoiler tines, depth of the subsoiling operation, soil moisture level, and soil texture (Swain, 1975). McEwen and Johnston (1979, p. 700) state that "the generally small effects obtained with rigid tine machinery elsewhere, even when plough pans are present, suggests that very intimate disturbance of the subsoil achieved by hand methods has substantially more effect on crop growth." They reported yield increases of 26% for barley (grain), 20% for wheat (grain), and 10% for sugar beets (storage root) grown in DD plots. Also, these increases were obtained in plots that had no initial growth-restricting horizon and received sufficient rainfall throughout most of the four-year study. Increases in the productivity of Italian ryegrass (El-Karouri and Gooderham, 1977), barley (Fisher et al., 1975), and sugar beets (Johnston and Warren, 1964) have also been reported following DD. In contrast, Dawkins et al. (1984) reported yield reductions in peas following deep hand tillage.

Although DD is not applicable on a large scale without specialized equipment such as the Wye Double Digger or Celli Soil Spader, it is being used by specialty producers and other small landholders. It also is being recommended to small landholders and families in developing countries. Because DD is the most time-consuming and laborious aspect of the intensive method, our study sought to isolate its effects on the yield of bush beans (*Phaseolus vulgaris* L.) and red beets (*Beta vulgaris* L.). We also examined soil parameters such as moisture level, strength, and nutrient availability, and plant parameters such as chlorophyll and nutrient content to complement our discussion of the effects of double digging on crop yield.

Materials and Methods

Experimental site and design

Field experiments were conducted at the Ohio University research garden site in southeastern Ohio during 1994 and 1995. The site is located approximately 100 m from the Hocking River on floodplain soil with a sandy loam texture (55% sand, 29% silt, 16% clay). Although the site had previously been under regular cultivation (mainly field corn), it had not been cultivated for approximately 15 years before this study and was maintained as turf in the interim. Before fertilization and cultivation each season, we took soil samples to establish initial soil nutrient levels (Table 1). There were no plow pans before cultivation, but the treatments described below did establish significant differences in soil strengths among treatments (see penetrometer readings). The 45-year running means for rainfall in June, July, and August, the months of study, are 88, 108, and 88 mm, respectively. We initially established three cultivation treatments in 1994 by hand digging. The experimental

Table 2. Application rate of soil amendments added, 1994 and 1995.

1994		1995	
Amendment	**Rate (kg/ha)**	**Amendment**	**Rate (kg/ha)**
Alfalfa Meal	355	Alfalfa Meal	1,022 (beets) 1,510 (beans)
Dolomitic Lime	1,000	Magnesium Sulfate	253
Sulfur	36	Sulfur	36
Borax	44	Borax	31
Compost (m^3/ha)	252	Compost (m^3/ha)	126 (beets) 252 (beans)

design was two completely randomized blocks separated by approximately 5 m, each with five replicate plots for each treatment, giving a total of thirty cultivated plots. Each plot was 1.5x1.5 m and received its respective cultivation treatment before planting each season.

Treatments

The three cultivation treatments were: SC (surface cultivation), loosening only the upper 5-6 cm of the soil with a sharp bladed hand-weeding tool; SD (single dig), loosening the soil to 25 cm with a spade; DD (double dig), loosening the soil to 50 cm with spade (top 25 cm) and fork (bottom 25 cm). We attempted to minimize mixing of subsoil and topsoil layers in the SD and DD plots. Other than cultivation, all plots were treated identically. These treatments are similar to minimum tillage (SC), conventional tillage (SD), and conventional tillage with subsoiling (DD) in mechanized farming systems.

During 1994, both blocks of 15 plots were planted with bush beans (cv. 'Tendercrop'). During 1995, one block was planted with bush beans and the other with red beets (cv. 'Red Ball'). We chose beans and beets to emphasize both above-ground and below-ground crops. All fertilizer amendments were organic and identical for each plot (Table 2). Before application, compost (primarily from horse manure) was thoroughly mixed and sifted through a 1.25-cm screen to ensure uniformity. The amounts of fertilizer application were based on recommendations by Timberleaf Soil Testing (Albany, Ohio) and were intended to provide sufficient nutrient levels for normal crop growth. Amendments were not incorporated beyond the top 5-6 cm of each plot, which avoided any further disturbance of the SC plots. All weeding was done by hand and no insecticides or herbicides were applied.

Soil and plant measurements

During 1994, we placed a single gypsum moisture block (Delmhorst, Towaco, N.J.) in the center of six randomly chosen plots per treatment at a depth of 6 cm, a depth chosen because it was the cultivation depth of the least disturbed treatment (SC). In 1995, we placed moisture blocks in three randomly chosen plots at depths of 6 cm and 25 cm for each treatment and crop. We took moisture readings (converted to soil water potential) every second day throughout each season, beginning at the 2-3 leaf stage. Daily precipitation and high/low temperature records were obtained from Scalia Laboratory on the Ohio University campus (approximately 1.5 km from the research site).

On June 8, 1994, we planted beans approximately 18 cm from each nearest neighbor in offset rows, using a template. The template gave very similar distribution and density patterns between plots. With this spacing, there was a potential maximum of 72 plants per 2.25 m^2 plot. We recorded germination rate for beans after 7, 9, and 11 days in 1994, and mean germination by treatment. Beans were planted on May 28, 1995 in the same manner, except that several seeds were planted in each location and thinned one week after germination to further insure equal densities among plots. For biomass comparisons among treatments in 1994, we randomly chose 10 plants from each plot and marked them with a numbered flag (100 plants per treatment). Beans (whole fruit) from marked plants were harvested on August 8, 16, and 23, 1994. The entire aboveground plant also was harvested on August 23. Therefore, the entire aboveground biomass accumulation was individually followed for 300 randomly chosen plants. In 1995, beans were harvested on July 15, 21, and 28 as above, except that the total number of plants was only 150. We recorded photosynthesis rate as CO_2 uptake ($\mu mol\ m^{-2}\ s^{-1}$) with an infrared gas analyzer (ADC, Model LCA3, Hoddesdon, England) for 10 plants per treatment on August 3, 8, and 11, 1994, and July 17, 1995. We examined photosynthesis rate because of its potential usefulness in interpreting yield differences following cultivation treatments.

Because of visually obvious chlorosis in SC bean plants during 1994, we took leaf samples (two 1 cm diameter disks per plant) from five randomly selected plants in each plot, for a total of 150 samples. Samples were taken from the central leaflet of the highest trifoliate in each plant. Chlorophyll was extracted with N,N-dimethylformamide (Moran, 1982; Inskeep and Bloom, 1985) and analyzed by spectrophotometer (Beckman, DU40 Series, Fullerton, California) for chlorophyll a and b, and total chlorophyll.

Beets (1995) were thickly planted on June 20, 1995 with a precision seeder (Earthway, Bristol, Indiana) in eight rows per plot separated by 15 cm. They were then thinned to 10-cm spacing between individual plants. As in the beans, this provided equal density and distribution patterns among plots. We harvested thirty randomly selected beet plants from each plot (450 total plants) on August 26, 1995 to measure individual root (edible portion) and green biomass. Also, the remaining beets in each plot were harvested for whole bed biomass. To assess differences in the rate of beet development, we measured leaf area index (LAI) weekly with an LAI-2000 Plant Canopy Analyzer (Li-Cor, Lincoln, Nebraska). Following beet removal in 1995, we took two penetrometer (Lang, Gulf Shores, Alabama) readings at 0, 5, 15, 25, 35, and 45 cm in three replicate plots per treatment.

All plant samples were weighed fresh and dry; dry weights were taken after samples maintained constant weight for 24 hours in a drying oven (Grieve, SB-350, Round Lake, Illinois). We calculated moisture content for individual plant samples and whole plants. To assess fertility

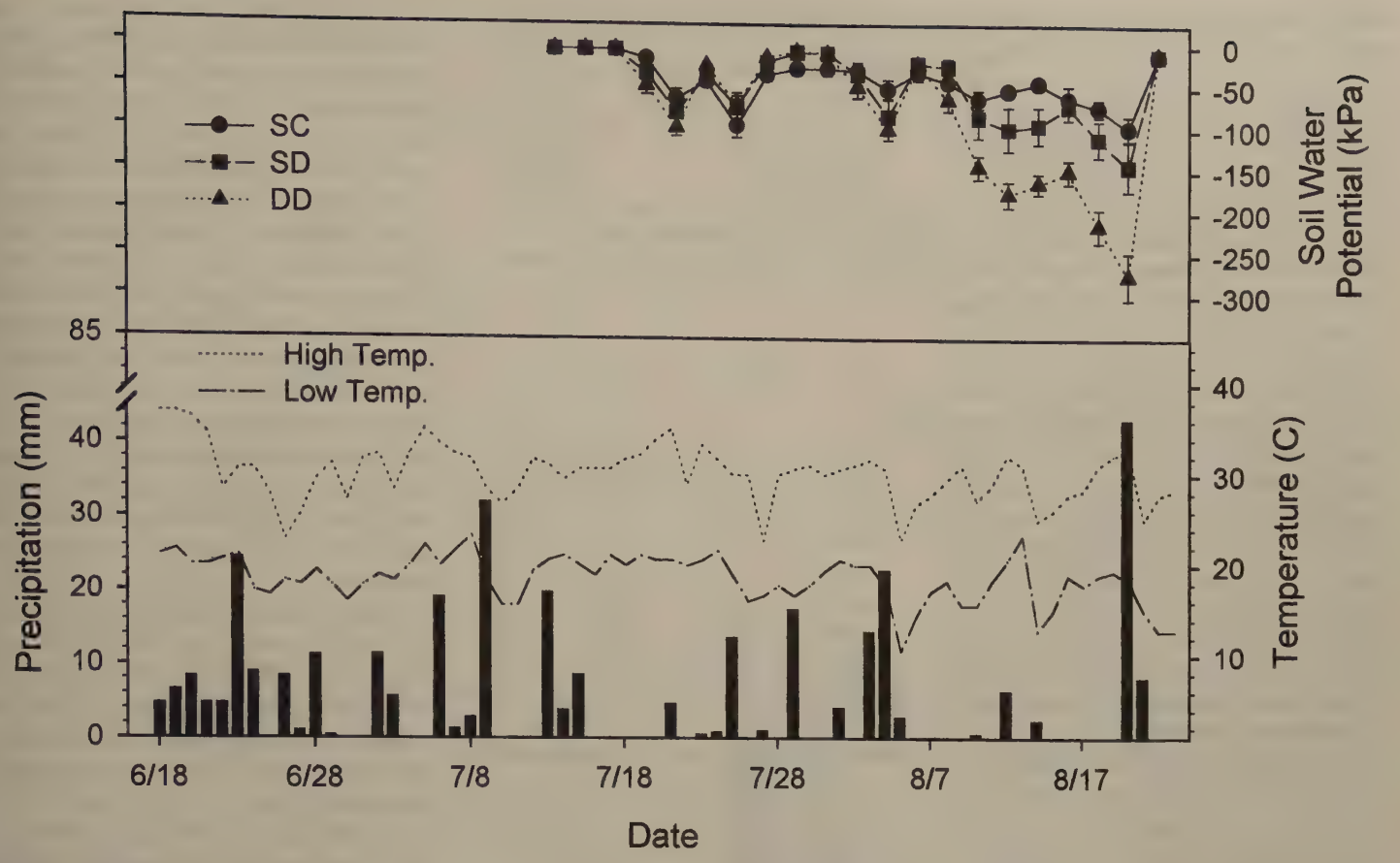

Figure 1. Temperature, precipitation, and soil moisture at 6 cm for bean plots, 1994. (The axis break in precipitation is included for consistency among all precipitation graphs.)

differences between plots, we took ten 15-cm deep soil cores from each treatment before cultivation each season. Samples were assayed for exchangeable Ca, K, and Mg by atomic absorption (Varian, Spectra AA-20, Victoria, Australia) after ammonium acetate extraction (Hendershot et al., 1993a). Soil pH and percent organic matter also were measured following the methods of Hendershot et al. (1993b) and Karam (1993), respectively. These data were used to complement the analysis of Ca, K, and Mg in beans (fruit) from the August 16, 1994 harvest and beets (root) harvested on August 26, 1995. We used beans from the second cropping of 1994 because this was the most productive harvest for all treatments and therefore supplied sufficient plant material. Thirty plant samples per treatment for each crop were ashed in a muffle furnace (Barnstead/Thermolyne, Model 62700, Dubuque, Iowa), acid digested, and analyzed by atomic absorption.

Statistical analysis

We used one-way analysis of variance (ANOVA) to test for treatment differences, unless noted below. Repeated measures ANOVA (RM-anova) was used for LAI, germination percentage, and moisture block measurements. Multivariate ANOVA (MANOVA, Wilks' Lambda test statistic) was used to test whether further analysis by ANOVA was statistically acceptable for all chlorophyll and plant ion readings because the respective data (i.e., chlorophyll a, b, and total chlorophyll, or Ca, K, Mg, and percent ash) were collected from the same samples. Assumptions of normality and equal variance were checked before ANOVA, and the data were transformed to meet these assumptions when necessary. When normality assumptions could not be met after several different transformations, we performed the Kruskal-Wallis one-way ANOVA (KW-anova, corrected for ties) on ranks. Nontransformed data are presented in all tables and figures. Significantly different treatment means ($p<0.05$) were separated by Bonferroni's all-pairwise multiple comparison procedure (MCP, $\alpha=0.05$). We performed all statistical analyses using NCSS (Version 6.0, Kaysville, Utah).

Results and Discussion

1994 - Beans

Rainfall exceeded the 45-year running mean for June, July, and August with 93 mm (+5%), 143 mm (+32%), and 131 mm (+49%), respectively. Figure 1 illustrates daily precipitation, temperature, and soil water potential records from initial planting to final harvest in 1994. RM-anova showed highly significant differences ($p<0.001$) for moisture readings at 6 cm (Fig. 1), with DD plots being significantly drier than both SC and SD plots (Bonferroni's MCP). Because of the unusually high rainfall, mean soil water potential never dropped below –300 kPa for any

Table 3. Mean (S.E.) chlorophyll a and b and total chlorophyll from bean leaves, 1994.

Treatment	Mean Chlorophyll (mg/g fresh weight)		
	a	b	Total[1]
SC	1.21a (0.03)[2]	0.332a (0.01)	1.54a (0.04)
SD	1.39b (0.03)	0.375b (0.01)	1.77b (0.03)
DD	1.39b (0.03)	0.371b (0.01)	1.76b (0.04)

[1] "Total" chlorophyll values are calculated, and therefore are slightly different from a + b.
[2] Means followed by the same letter in a column are not significantly different (p=0.05, Bonferroni's MCP).

Table 4. Soil analysis by treatment[1], 1994 and 1995.

Soil Component (mmol/100 g)	1994			1995		
	SC	SD	DD	SC	SD	DD
Ca	1.71	1.73	1.79	4.77	4.67	5.01
Mg	1.08	1.19	1.04	1.27	1.27	1.42
K	0.54	0.80	0.67	0.61	0.72	0.63
Organic matter (%)	5.29	5.23	5.56	4.93	4.87	5.19
pH[2]	5.87	5.91	5.86	6.71	6.73	6.74

[1] There were no significant differences (p<0.05) among treatments in either year for any of the measured soil components.
[2] Statistical analysis of pH was performed on hydrogen ion concentration and then converted back to pH.

treatment. From the shallow depth of these readings and the lack of noteworthy water deficits, it can be inferred that there was no extreme water stress (water potential readings below −1,000 kPa) for plants in any treatment. Therefore, results from 1994 should be similar to those expected in irrigated fields.

There was no significant difference (p= 0.65, RM-anova) in total germination among treatments after 11 days. The overall germination rate for all treatments was 69±1.1% (57 plants per 2.25 m^2 bed). Photosynthetic rates among treatments did not differ significantly (p<0.05) on any of the three dates examined. Mean (S.E.) photosynthetic rates for all treatments on August 3, 8, and 11 were 12.2 (0.3), 17.7 (1.3), and 21.4 (0.9) $\mu mol\ m^{-2}s^{-1}$, respectively.

As the season progressed, beans in SC treatment plots exhibited visually obvious chlorosis while plants in SD and DD plots appeared much greener. Other researchers have reported similar results after deep tillage (El-Karouri and Gooderham, 1977; Dawkins et al. 1984). MANOVA on data collected from leaf chlorophyll extractions indicated highly significant (p<0.001) differences among treatments. Further separation by ANOVA and MCP indicated that leaf samples from SC treatment plots had significantly less chlorophyll a and b and total chlorophyll than samples from SD and DD plots (Table 3). There was no difference between SD and DD plots.

Table 5. Tissue cation analysis by treatment[1] for bean fruits, 1994, and beet roots, 1995.

Cation (mmol/100 g)	1994 - Bean Fruits			1995 - Beet Roots		
	SC	SD	DD	SC	SD	DD
Calcium	15.3	14.5	15.3	4.9	4.4	3.9
Magnesium	12.2	11.8	12.0	18.1	18.0	17.5
Potassium	63.3	67.9	67.1	126.9	127.3	117.4
Ash Content (%)	7.2	7.6	7.3	12.6	12.5	12.0

[1] There were no significant differences (p<0.05) among treatments as measured by MANOVA.

The chlorophyll data suggested either differences in soil nutrient content among treatment plots or reduced root exploration and nutrient extraction by plants in the SC plots. Soil tests (Table 4) performed on individual treatment plots for Ca, Mg, K, organic matter, and pH indicated no significant differences (p<0.05) among treatments. Deep hand tillage (both SD and DD) appears to improve leaf chlorophyll content, possibly because of increased soil exploration by bean roots and improved nutrient acquisition. Most subsoiling research shows significant increases in total root biomass and rooting depth following deep tillage (Dawkins et al., 1984; Marks and Soane, 1987; Harrison et al., 1994) and, therefore, supports the previous statement.

Fruit samples showed no significant differences (p=0.29, MANOVA) in Ca, Mg, K, and ash content (Table 5) among cultivation treatments. Barber and Navarro (1994) performed foliar analysis on maize, soybean, sunflower, and wheat for a several ions (B, Ca, Cu, Fe, K, Mg, Mn, N, P, S, and Zn) and found that mechanical subsoiling had no affect on nutrient uptake. Some researchers have found that deep hand tillage improves nutrient uptake in crops (El-Karouri and Gooderham, 1977), while others found no increase (McEwen and Johnston, 1979). Nutrient uptake for SC plants apparently was only slightly affected (i.e., reduced chlorophyll) by the lack of deep tillage. Under lower precipitation or lower soil nutrient status, this difference in nutrient uptake might become visible in the edible fruits.

Mean moisture content for aboveground bean plants (three harvests plus final harvest of stems and leaves) was significantly less (H=9.67, p=0.008, KW-anova) in the DD plots than in the SC plots. Mean (S.E.) moisture content for entire aboveground plants was 87.7 (0.1), 87.6 (0.1), and 86.8 (0.4)% for the SC, SD, and DD treatments, respectively. There were no significant differences (H=2.18, p= 0.34, KW-anova) in the moisture content of fruits among treatments.

ANOVA on total aboveground dry biomass accumulation (Fig. 2) showed significant differences (F=3.21, p=0.042). SD plots were more productive than SC plots, but there was no difference between the

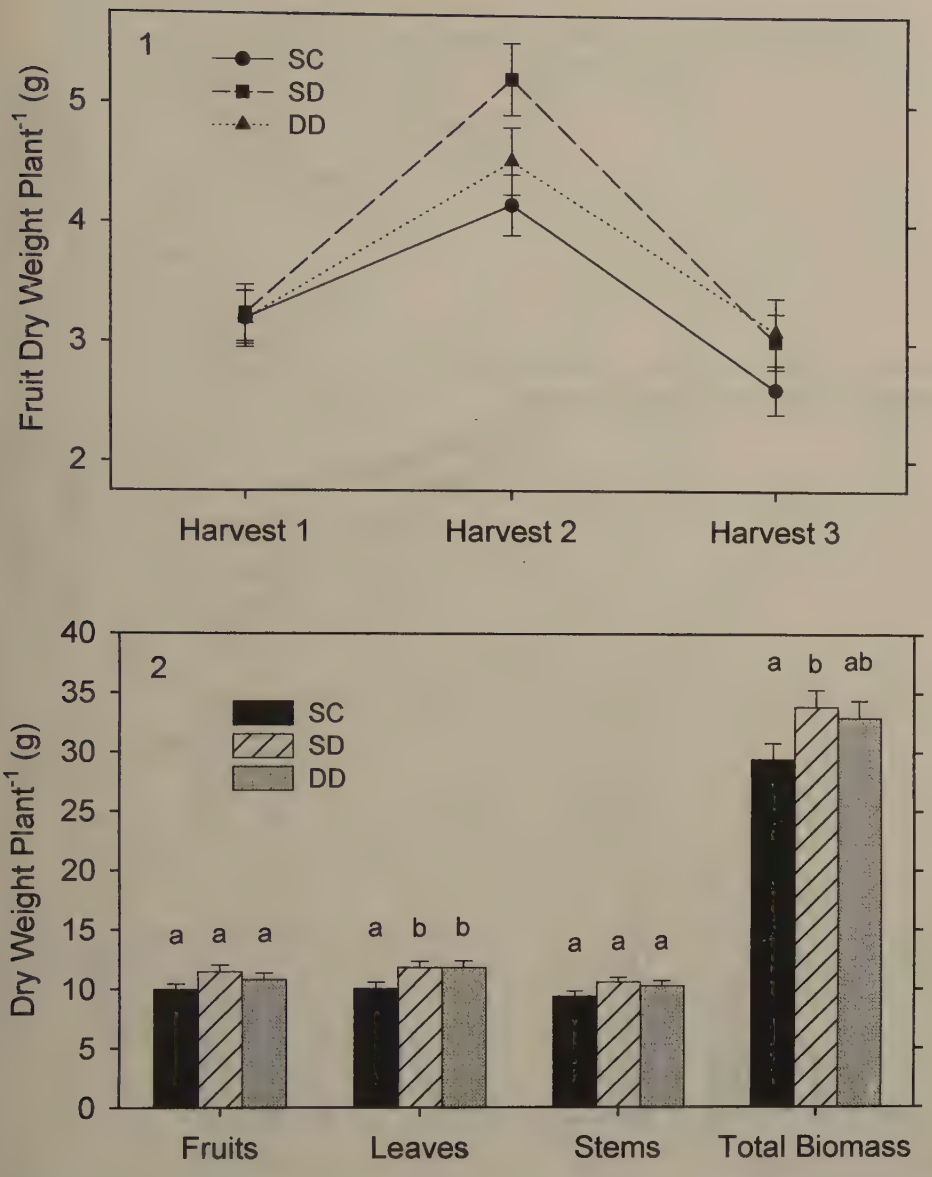

Figure 2. Bean harvest, 1994. 1. Mean dry fruit biomass per plant, by treatment and harvest date. 2. Mean dry biomass per plant for all aboveground plant components, separately and combined.

DD plots and other treatments. When components of individual plants were compared (Fig. 2), only leaves were significantly different (F=4.26, p=0.02) among treatments, with both SD and DD plots producing more leaf biomass per plant than SC plots. Comparisons of total stem and fruit production per plant were not significantly different among treatments (F=2.53 [p=0.08] and F=1.94 [p=0.15], respectively). The mean (S.E.) per plant biomass of dry fruits was 9.9 (0.5), 11.4 (0.6), and 10.8 (0.6) g for the SC, SD, and DD treatment plots, respectively. From the above data, it can be seen that throughout 1994 there were very few differences among treatments.

1995 - Beans

Rainfall again was greater in June and August than the 45-year running mean, with 103 (+17.1%) and 114 (+29.6%) mm, respectively (Fig. 3). July 1995 was considerably drier than normal, with only 60 mm of precipitation (–44.4%). As in 1994, none of the treatment plots experienced appreciable water stress (Fig. 3). There were no significant differences in soil water potential among treatments at 6 cm (p=0.81). There were significant differences at 25 cm (p=0.02), with DD treatment plots losing moisture at a faster rate than SC plots. Drier soil profiles in more deeply tilled plots (SD and DD) are likely the result of differences in both soil compaction and plant water uptake (Greenwood and Cameron, 1990; Harrison et al., 1994).

Photosynthesis readings were taken on one date (July 17) in 1995 and were not significantly different (F=2.01, p=0.15) among treatments. Mean moisture content for the entire aboveground plant in 1995 was significantly different (H=11.70, p<0.003, KW-anova), with DD plants containing less moisture (85.7±0.1%) than SC plants (86.2±0.2%). SD plants (85.9±0.2%) were not significantly different from the other treatments. There were no significant differences (H=4.92, p=0.09) in fruit moisture content among treatments, and the combined mean for all plots was 89.8±0.1% moisture. Figure 4 shows the results of each fruit harvest and mean production per plant for the individual and combined components of aboveground biomass. The mean (S.E.) biomass of dry fruits per plant was 7.3 (0.7), 6.9 (0.6), and 7.5 (0.7) g for the SC, SD, and DD treatment plots, respectively. There were no significant differences among treatments for fruits (F=0.09, p=0.91), leaves (F=1.38, p=0.26), stems (F=0.63, p=0.54), or total aboveground biomass (F=0.62, p=0.54). From Figure 4, it is apparent that the previous season's trend toward higher yield in SD plots was not repeated.

1995 - Beets

Although the beet plots received sufficient moisture early and late in the growing season, the soil profile dried substantially during midseason (Fig. 5). Individual treatment plots experienced soil water potentials as low as –1,700 and –1,500 kPa at 6 cm and 25 cm, respectively. There were no significant differences (p=0.87, RM-anova) in soil water potential among treatments at 6 cm, but there was a significant difference (p=0.043) at 25 cm. SD plots were drier than SC plots at 25 cm, with no difference between DD plots and the other treatments. The lack of difference in soil moisture among treatments at 6 cm was likely due

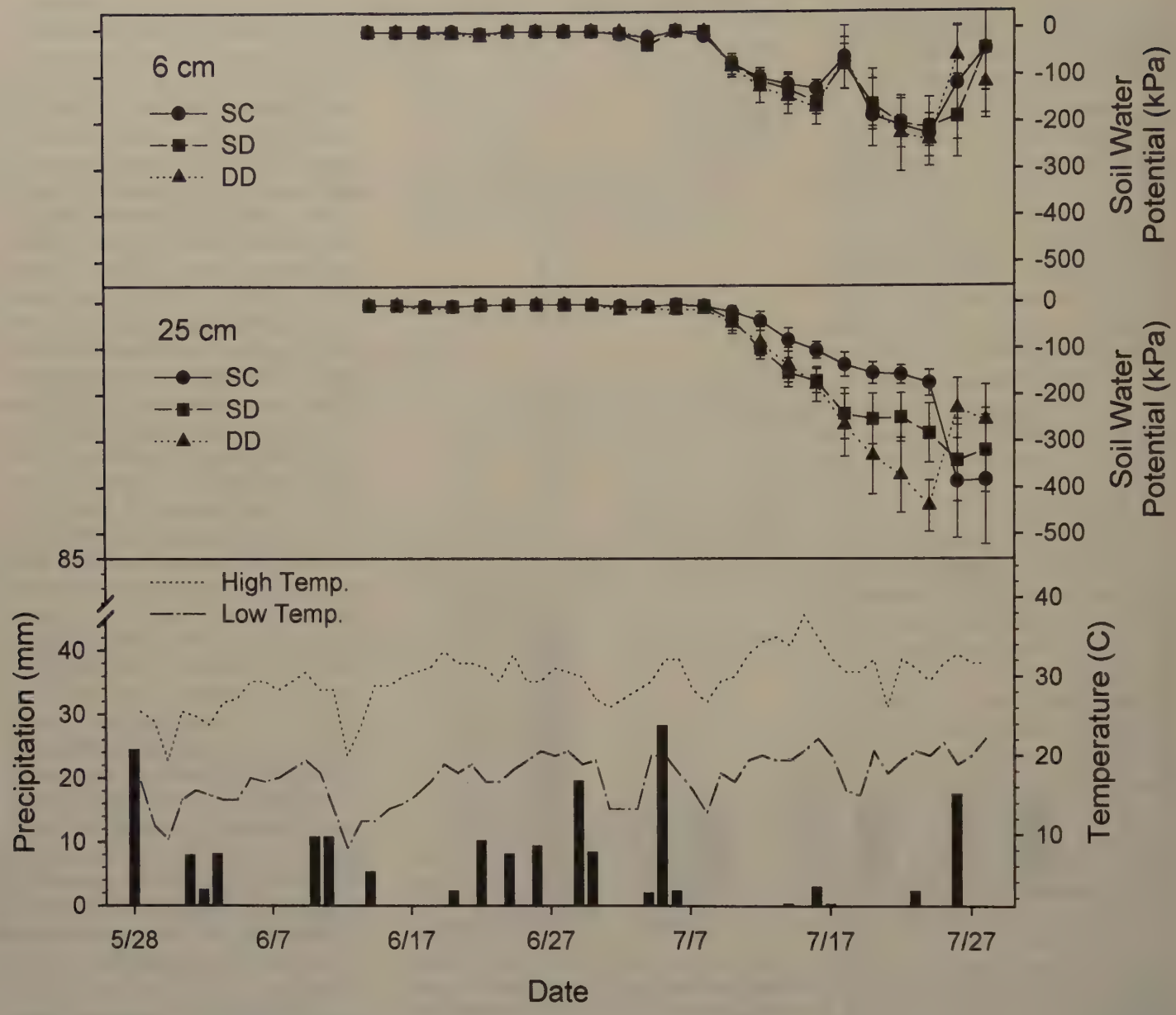

Figure 3. Temperature, precipitation, and soil moisture at 6 and 25 cm for bean plots, 1995.

to the tightly closed canopy during drier weather.

LAI readings (Fig. 6) taken throughout the season were not significantly different (p=0.19, RM-anova), which indicates that rates of aboveground biomass development were uniform among treatments. This result was surprising considering the hot, dry conditions of July, where deep hand tillage might have been expected to confer significant advantages. At harvest, cross sections of roots from all treatments showed the white rings typical of beets grown under periodic water stress.

There were significant differences in moisture content for leaves (H=18.78, p<0.001, KW-anova) and roots (H=7.55, p=0.023, KW-anova) among treatments. The mean (S.E.) moisture content for leaves of SC, SD, and DD plants was 90.9 (0.1), 90.4 (0.1), and 90.5 (0.1)%, respectively. Leaves from SC plots had significantly more moisture than leaves from either SD or DD plots. For edible roots, the moisture content was 90.0 (0.2), 89.7 (0.2), and 89.3 (0.2)% in SC, SD, and DD plots, respectively. The only significant difference for roots was between SC and DD plots. Therefore, for both crops in both seasons, SC treatment plants tended to have slightly higher moisture contents, although these differences were always very small and probably did not reflect an important ecological trend.

As indicated in the introduction, the effects of deep tillage on crop productivity are normally expected to be more pronounced under dry conditions. Nevertheless, there were no significant differences among treatments in the biomass production of beet leaves (H=3.21, p=0.20, KW-anova) or roots (F=0.22, p=0.81) (Fig. 7). The mean (S.E.) biomass of dry leaves per plant was 7.4 (0.3), 7.8 (0.3), and 8.5 (0.4) g for SC, SD, and DD plots, respectively.

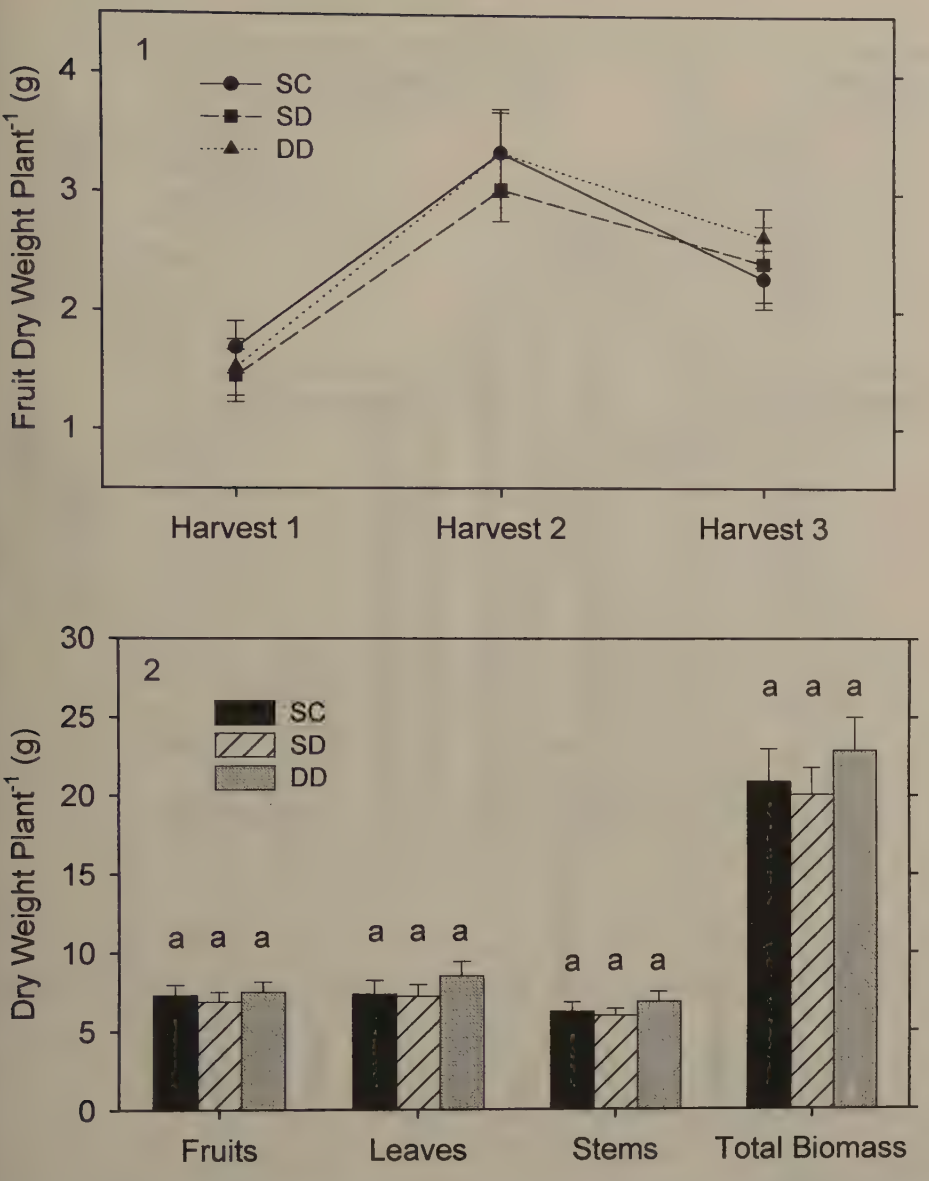

Figure 4. Bean harvest, 1995. 1. Mean dry fruit biomass per plant, by treatment and harvest date. 2. Mean dry biomass per plant for all aboveground plant components, separately and combined.

Respective mean biomasses of beet roots in SC, SD, and DD plots were 10.4 (0.5), 10.9 (0.5), and 10.6 (0.6) g per plant. As in 1994, soil tests on Ca, Mg, K, organic matter, and pH were not significantly different ($p<0.05$) among treatments (Table 4). These data on soil nutrient levels in 1995 were taken before fertilizer amendments for the second season, but after approximately nine months in which the plots had no cover crop. The absence of significant differences in soil nutrient levels may indicate that the SD and DD treatments did not significantly alter nutrient leaching patterns in these plots.

Beet roots (Table 5) were not significantly different among treatments for Ca, Mg, K, or percent ash as determined by MANOVA ($p = 0.28$). Beets showed almost no treatment variability with respect to aboveground growth rate, biomass accumulation (roots or leaves), or nutrient uptake despite the markedly dry conditions in July, 1995.

Penetrometer readings

Directly after the beets were removed in 1995, we took penetrometer readings to a depth of 45 cm (Fig. 8). Disturbances related to beet crop removal were limited to the top 3-5 cm of soil in each plot and had essentially no affect on these readings. There were significant differences ($p<0.05$) in penetration resistance at four of the six depths sampled, with SC plots exhibiting soil strengths greater than 2,000 kPa throughout their entire profile. SD and DD treatment plots did not have soil strengths greater than 2,000 kPa for the upper 25 cm of their respective profiles, and DD plots consistently had the lowest soil strength of the three treatments.

Very little information is available concerning the direct relationship between soil strength and crop yield. Schmidt and Belford (1994) demonstrated that with progressively deeper tillage there are associated reductions in soil strength and increases in wheat grain production. Their data suggest predictable, linear improvements in crop yield with reductions in soil strength. This differs from the view that there will be little or no difference in yield unless tillage disrupts a well-defined plow pan (Swain, 1975). Ouwerkerk and Raats (1986) state that for sandy soils, root crop fanging (split roots) may be caused by soil strength greater than 2,500 kPa. Nevertheless, soil strength varied significantly among treatments in the present study, with almost no corresponding differences in bean or beet yields. This is likely due to overriding factors such as high soil moisture and sufficient soil nutrient content.

Conclusions

This study provides quantitative information on the productivity of bush green beans and red beets in a sandy loam soil following deep hand tillage. The data were collected in a system that was well amended with organic fertilizers and compost. Also, soil moisture content from natural rainfall generally was sufficient to avoid crop stress. Although there were significant differences in soil strength among treatments, there were no associated crop responses for the marketable portions of either crop. There also were no differences in their contents of several ions.

Most of the literature shows that while mechanical subsoiling may have a substantial effect in dry seasons, it has little

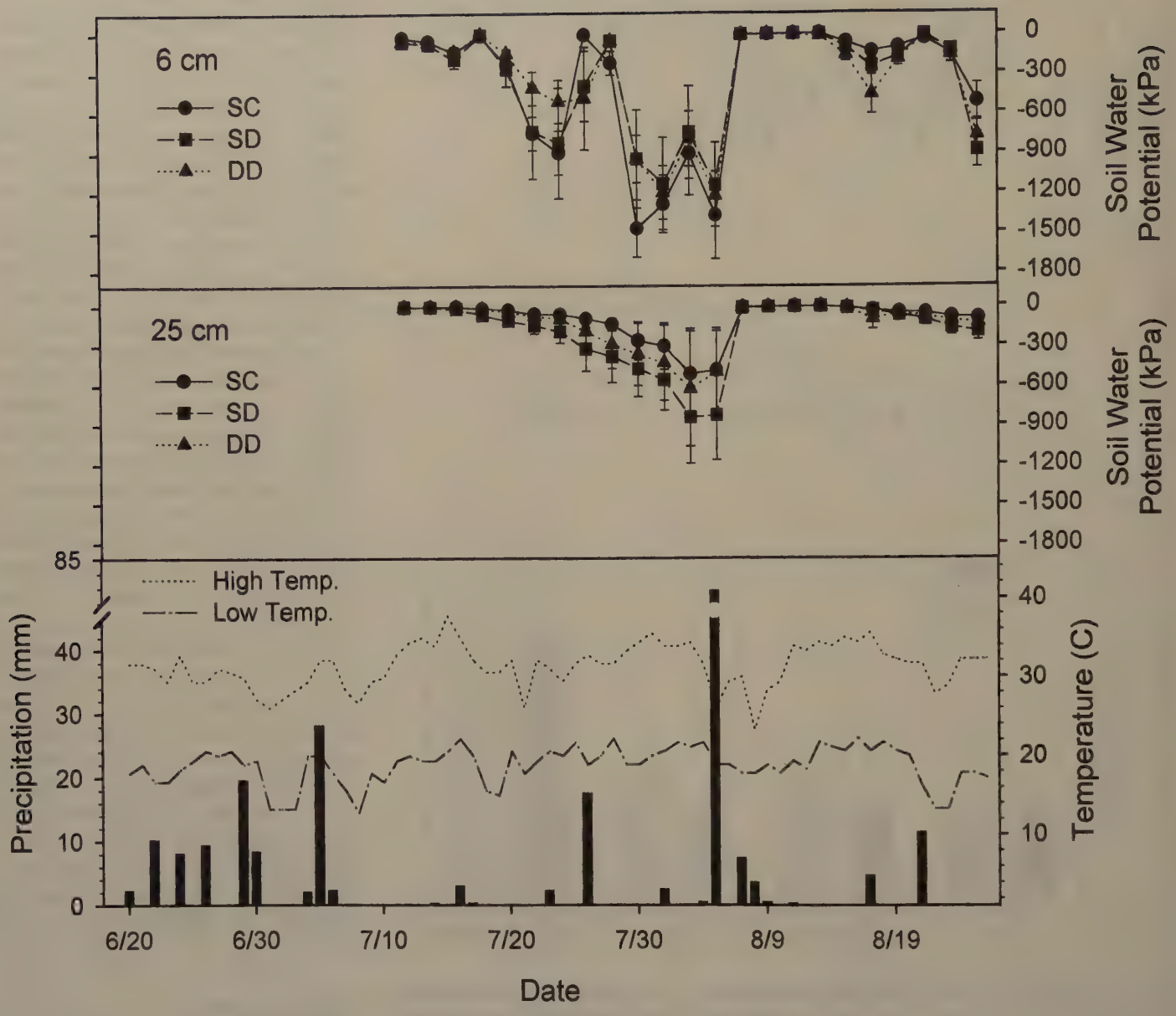

Figure 5. Temperature, precipitation, and soil moisture at 6 and 25 cm for beet plots, 1995.

impact on crop yield under sufficient natural moisture or irrigation. For double digging by hand, which increases the degree of subsoil disturbance compared with conventional mechanical tillage, our results demonstrate that crop response to hand cultivation is similar to that expected from mechanical subsoiling. Lipiec and Stepniewski (1995) report that in well-watered and high fertility conditions, moderate compaction may benefit the transport of nutrients to the roots. In dry locations where irrigation is limited and soil compaction restricts root growth, the literature recommends deep tillage. In dry seasons there may be substantial increases in yield, but these benefits may not be economical. That is, even with a yield increase from deep tillage during dry seasons, the costs of production may remain higher than the revenue from selling the crop (Ross, 1986). Therefore, even after deep tillage, irrigation may be necessary to maintain profitable yields during dry seasons (Ross, 1986; Soane et al., 1987; Greenwood and Cameron, 1990).

For small landholders and people producing for their own use, these economic considerations are irrelevant, and any yield increase may be important. Small-scale crop production also differs from large-scale mechanized operations with respect to soil recompaction. Because of wheel traffic, mechanical subsoiling must be repeated every one to four years (Bennie and Botha, 1986; Soane et al., 1987; Vepraskas et al., 1995). Without wheel traffic, the effects of deep tillage should last indefinitely, assuming well-planned crop rotations that include winter cover crops.

Because of the high labor and energy

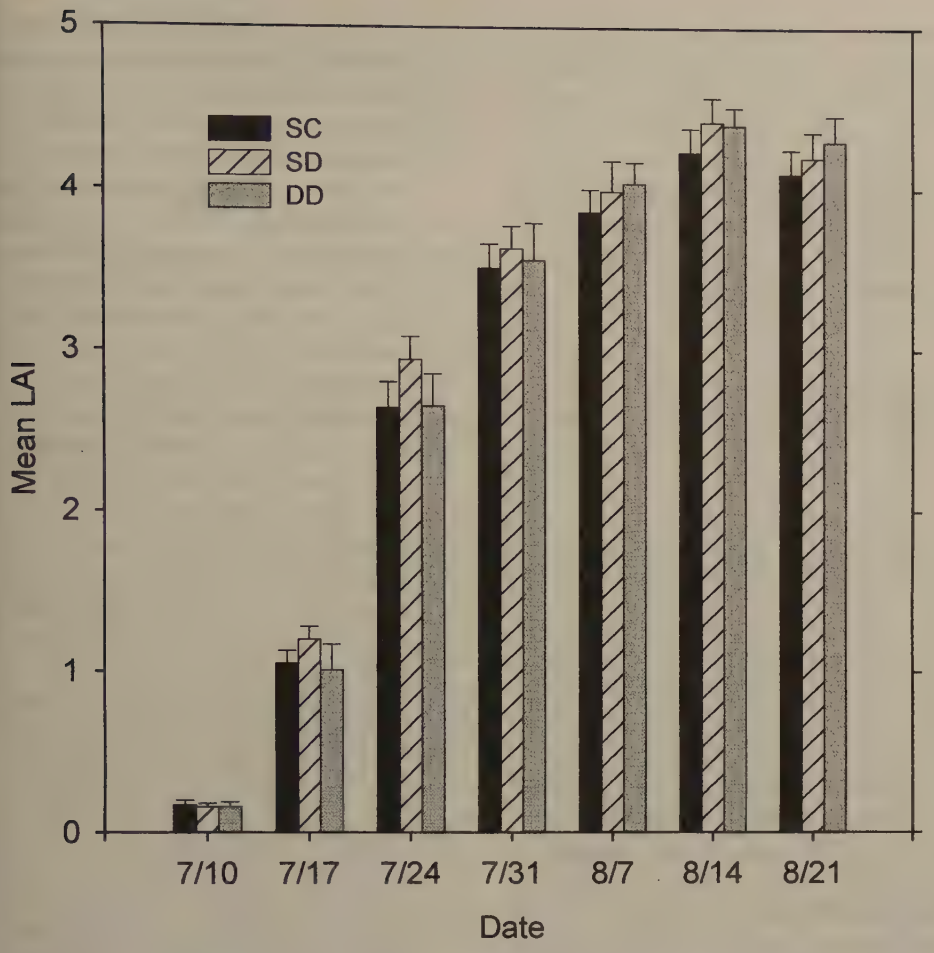

Figure 6. Mean weekly leaf area index readings for beets by treatment, 1995.

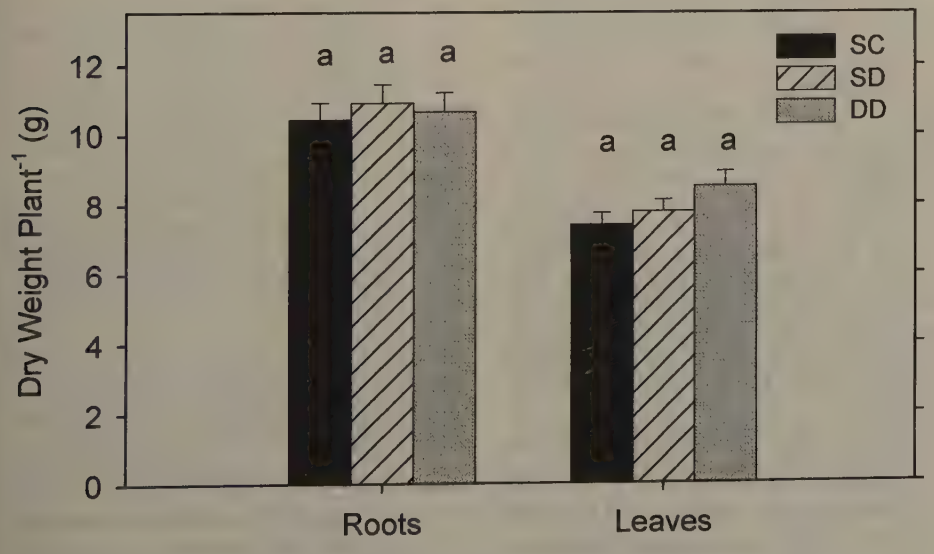

Figure 7. Mean dry biomass per plant of beet roots and leaves, 1995.

costs of double digging, the results from this study suggest that it should be avoided in locations with sufficient rainfall, moderate to high soil fertility, and no definite root-restricting soil horizons. Because the effects of deep hand tillage have received little attention to date, we designed this study to act as a starting point for further research. Plants were given sufficient nutrients and moisture. The present study does not address plant productivity under severely limited supplies of nutrients or moisture, an area that clearly requires further investigation. Where there are restricting horizons or resource limitations, the small-scale farmer might consider double digging once, followed by continued proper bed management. Because many physical, chemical, and biological soil properties are greatly enhanced by adopting a no-till strategy (Karlen et al., 1994), avoidance of unnecessary tillage practices is further supported.

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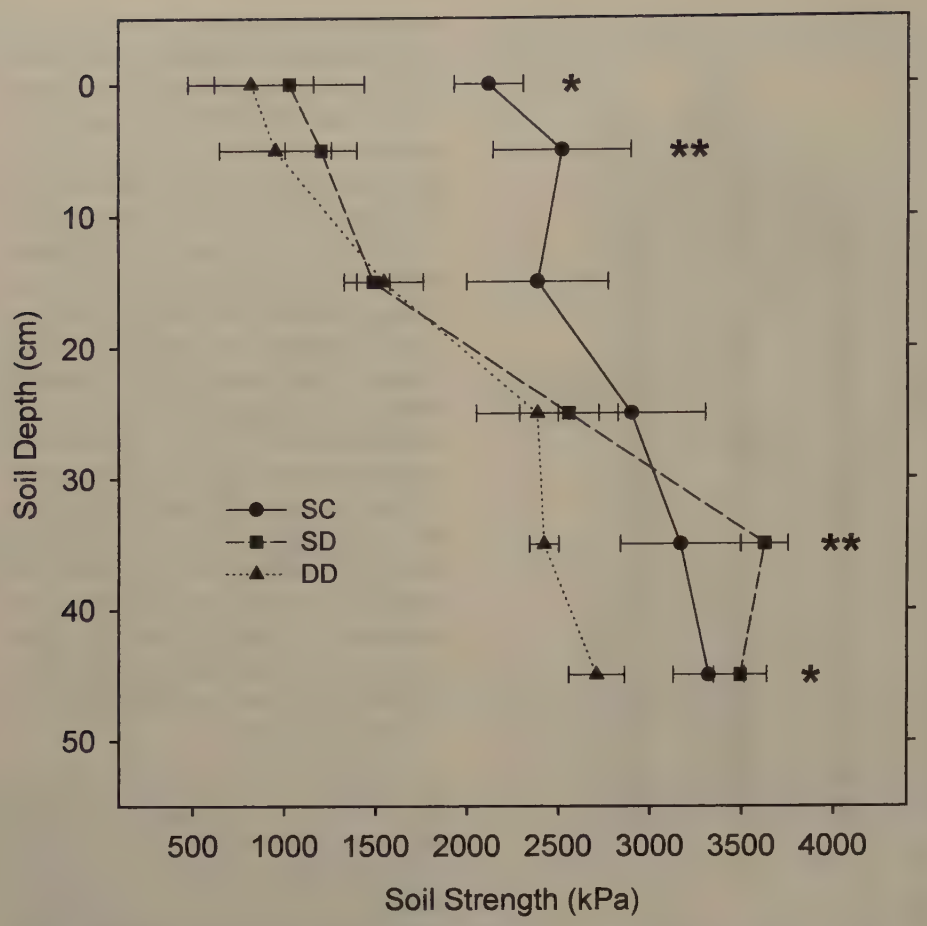

Figure 8. Soil strength measurements by treatment at various depths, 1995. (Means at a given depth followed by * and ** are significantly different at p<0.05 and p<0.01, respectively.)

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EMPHASIZE SUSTAINABLE AG, SMALL FARMS COMMISSION RECOMMENDS

One of the policy goals recommended in the USDA National Commission on Small Farms' report to USDA Secretary Dan Glickman, released in late January, is to "emphasize sustainable agriculture as a profitable, ecological, and socially sound strategy for small farms." The pace of industrialization of agriculture "has quickened," according to the 120-page report, entitled "A Time to Act." "The dominant trend is a few, large, vertically integrated firms controlling the majority of food and fiber products in an increasingly global processing and distribution system. If we do not act now, we will no longer have a choice about the kind of agriculture we desire as a Nation."

The Commission outlined eight policy goals for a national strategy for small farms in its report, and stated that "sustainable agriculture integrates three main goals—environmental health, economic profitability, and social and economic equity. Farming systems that simultaneously pursue these three goals hold great potential for maintaining the viability of small farms, and they contribute to the well-being of rural communities and stewardship of our natural resources." To meet that goal, the Commission made 16 recommendations, including:

- The USDA Office of Communications should develop and conduct a communications campaign to inform farmers of the new farming systems, strategies, practices, and technologies emerging from the 10 years of SARE research.
- Cooperative Extension, Natural Resources Conservation Service, and Farm Service Agency field staff should identify places where small farms have particularly high reliance on pesticide and nutrient use, and provide those farmers with information on sustainable practices.
- The Office of Communications should develop an effort on organic farming to coincide with the publication of the final rule for the national organic standards.
- The USDA Office of Outreach should work with the President's Commission on Sustainable Development to link citizens interested in sustainable development with sustainable agriculture and farmers.
- The Cooperative State Research, Education, and Extension Service should encourage land-grant university colleges of agriculture to offer courses in sustainable agriculture and organic farming as electives for degrees in agriculture.

Another policy goal is to "dedicate budget resources to strengthen the competitive position of small farms in American agriculture," which includes a recommendation to increase appropriations for the SARE program by $10 million each year over three years to reach its authorized funding level of $40 million, and to fund the SARE Chapter 3 Professional Development Training Program at $10 million.

"We look forward to joining with you and others in helping to fashion policies, programs, and partnerships that will bring economic vibrancy to rural communities, wholesome and nutritious food for consumers, stability to our small farm enterprises, and an improved quality of life to our small farmers and our farmworkers," the members of the Commission wrote.

Appointed by Secretary Glickman in July, 1997, the Commission has 30 members, including two members of the Wallace Institute's Board of Directors: Commission Vice Chair Desmond Jolly of California, and Frederick Magdoff of Vermont. Its report is available from Jennifer Yezak Molen, (202) 720-0122; e-mail smallfarm@usda.gov; from the National Commission on Small Farms, P.O. Box 2890, Washington, D.C. 20013; or on the USDA's Web site at http://www.usda.gov/news/news.htm.

Creating positive incentives for farm composting

Richard M. Kashmanian and Robert F. Rynk

Abstract. *With the growing concern about the impact of agriculture on water quality and heightened interest in managing agricultural by-products economically, the use of composting by U.S. farmers is increasing. Over 8,000 farms are now composting animal mortalities, manure, crop residues, and selected organic materials from communities and industries. At least 75% of farm composting operations are composting poultry mortalities. Based on discussions with contacts in leading agricultural states and organizations, this paper provides examples of technical and economic incentive programs encouraging farmers to adopt composting as a way to manage farm by-products. These programs have been established largely by the public sector, including state agencies, public universities, USDA, and USEPA. However, they are often initiated by or conducted in partnership with the private sector entities such as farms, livestock and poultry product companies, and composting businesses. Examples of incentive programs include research and demonstration projects, extension educational programs, technical standards, regulatory incentives, cost-sharing, financial grants, and low-interest loans. Many projects have succeeded in expanding the practice of composting among farms. For example, the now common practice of composting poultry mortalities can be traced to research and educational programs at the Universities of Maryland and Delaware, which were followed by a national technical standard adopted by the USDA. Similar success stories are apparent in other composting incentive programs, such as for composting of swine mortalities in Missouri, dairy manure in Michigan, and non-farm materials in California and Pennsylvania.*

Keywords: manure, mortalities, dairy, poultry, swine

In 1995 and 1996, we gathered information about agricultural composting from representatives of agricultural and environmental organizations in leading agricultural states and states known to be actively promoting farm composting. Our purpose was to assess the status and trends of farm composting in the United States, including the number of farmers practicing it, their reasons, the methods used, how and where the compost is used, and motivating and impeding factors for farmers to compost. Much of the information gathered was reported by Kashmanian and Rynk (1996).

From this work and previous studies (Kashmanian, 1994; Rynk, 1994; Poultry Water Quality Consortium, 1997), it is evident that interest in farm composting is growing. Over 8,000 farms are currently composting in the United States. By far, most are poultry operations, composting bird mortalities generated on-site. Only a small percentage of farms compost manure or crop residues, though the numbers are increasing. Most farm composters have adopted composting within the past five years, for various reasons, including: loss of traditional methods to handle livestock and poultry mortalities (e.g., rendering facilities, burial pits, landfills); constraints on direct land application of manure and crop residues (e.g., loss of land, odors, regulations, weed seeds, high C:N ratio); potential to improve the quality and use of manure (e.g., fewer weed seeds, more consistent spreading, reduced volume); and potential revenues from the sale of compost.

The factors that induce farmers to become composters affect the geographic distribution of composting farms. Nationwide, composting tends to be more prevalent in the East and Midwest because lack of agricultural land and high population densities tend to favor composting. Nevertheless, composting also is gaining attention in the West, particularly in California. Furthermore, the distribution of composting farms suggests that other influences are affecting farmers' decisions regarding composting. Even within a given region, farms that have turned to composting tend to be concentrated in states where farm composting is actively promoted.

Public and private efforts have encouraged composting through economic incentives, educational programs, farm demonstrations, information and technical assistance, research and diffusion of research, and streamlined regulatory mechanisms. These incentive programs are divided into two categories for this paper: technical and economic.

Most programs promoting farm composting are conducted by public agencies and organizations. Typically they are offered by public land-grant universities, state agricultural and environmental agencies, the U.S. Department of Agriculture (USDA), or the U.S. Environmental Protection Agency (EPA). However, several private sector groups also promote farm composting, including nonprofit interest

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This paper is based on a presentation made at the European Commission's International Symposium, "The Science of Composting," in Bologna, Italy, May 30-June 2, 1995.

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groups, livestock and poultry processing companies, and composting equipment or service businesses.

Many incentive programs are a result of partnerships between public and private organizations. In a typical scenario, an industry group that represents a particular agricultural commodity and is interested in reducing its impact on the environment might approach a state agency for information or guidelines regarding a specific composting application. The state agency may then turn to the land-grant university or USDA's Natural Resources Conservation Service (NRCS) to provide aid or to develop the information and disseminate it through demonstrations or educational programs. This often will take place with assistance from the commodity group. In addition, organizations cooperatively carry out composting promotional programs, sharing expertise and outreach channels. Good examples can be found in the partnership between Rodale Institute and Pennsylvania State University Cooperative Extension and in the collaborative efforts of public and private organizations in Massachusetts and Maine.

Technical Incentive Programs

Widespread composting of poultry mortalities started in the Delmarva region (Delaware, nine Eastern Shore counties of Maryland, and two Eastern Shore counties of Virginia), and was stimulated by research and extension programs at the Universities of Maryland and Delaware. This led to adoption of a national standard for poultry mortality composting by the NRCS and support for composting within the poultry industry. This trend then spread to other poultry-producing states (Kashmanian, 1995), usually following research and education by state universities. The same pattern is evident in the trend toward composting swine mortalities, with Missouri leading the way.

Based on its work for the Missouri Department of Natural Resources (DNR), the University of Missouri developed a state standard for composting swine mortalities (Fulhage and Ellis, 1994). The standard reflected the DNR's interest in an alternative to disposal pits that could be widely adopted by swine farms. As a result, operational procedures and cost were important considerations in the formation of the standard.

In South Carolina, a swine industry trade publication carried a story about the University of Missouri's research on composting swine mortalities. Because of their general unhappiness with burial pits and the lack of rendering facilities, and with some counties prohibiting the disposal of swine mortalities in municipal landfills, the state's swine industry approached the NRCS state office with this information and asked them about swine mortality composting. With NRCS assistance, two farms received trial permits to compost swine mortalities. The composting evaluation phase has been successfully completed. Composting is now a recommended way to handle swine mortalities in South Carolina. Based on these field trials and the influential work done at the University of Missouri, the NRCS office is developing a state standard for composting swine mortalities with procedures that include broiler litter or sawdust.

It is important that consideration be given to how regulations are written. Regulations need enough flexibility to allow for modifications as new technology becomes available. In at least one case (Arkansas), state regulation limited the size of carcass pieces for composting to 60 lb, based on the then-current state of knowledge. On the other hand, swine carcasses weighing up to 650 lb have been successfully composted. The Arkansas state regulatory agency granted Arkansas agricultural agencies an exemption from the 60-lb state requirement to permit composting whole swine carcasses. The NRCS and Cooperative Extension Service have developed design criteria, standard engineering drawings, and operation and maintenance methods for composting swine mortalities for statewide implementation without a size limitation. Other states are in the process of adopting the concepts, methods, and procedures based on the Arkansas demonstrations. In addition, the 60-lb limit is no longer in place in Arkansas.

Since 1987, Massachusetts has actively promoted on-farm composting. As a result, over 100 Massachusetts farms are "registered" agricultural composters. The state has sponsored farm composting educational programs (conferences, workshops, and tours) and funded many research and demonstration projects. These activities have been developed and conducted by the Department of Food and Agriculture (DFA), in partnership with the Department of Environmental Protection, the University of Massachusetts, and private groups, including the New England Small Farm Institute and the Massachusetts Farm Bureau. Massachusetts also has established flexible regulations for farms to compost on-farm and off-farm materials. In most cases, farms need to register with DFA but are not required to obtain permits.

In Maine, similar cooperation among state environmental and agricultural agencies and the University of Maine has resulted in several successful and novel composting applications, including potato culls, dairy manure, telephone books, and by-products from fish and blueberry processing. Maine farms also can compost off-farm materials without great regulatory burden.

In New Jersey, state legislation transferred oversight responsibility for on-farm leaf composting from the state's Department of Environmental Protection to its Department of Agriculture. In addition, the N.J. Department of Agriculture, through the state Soil Conservation Committee, is developing criteria and standards for on-farm manure composting. These rules will facilitate handling of farm composting through local soil conservation districts.

The California Integrated Waste Management Board (CIWMB) funded agricultural composting demonstration projects to encourage farm composting, compost use, and direct land application of clean organic materials. One of CIWMB's objectives is to recycle community-generated organic materials within agriculture, to the benefit of the farms and communities. Promotional efforts include six large-scale demonstration projects focusing on the use of compost and organic mulch by commercial growers. The demonstration projects are dispersed throughout California and encompass a variety of agricultural commodities, including cotton, tree fruits, onions, vegetables, and grapes. The projects are carried out in collaboration with

commercial growers, compost producers, local government representatives, Cooperative Extension advisors, and university researchers. Also, education and outreach activities have been conducted to promote the use of compost and strengthen compost markets. While the projects appear to have heightened farmers' interest, increases in composting and the use of compost have not been ascertained.

Several operations producing compost for commercial growers have been financed in part by CIWMB's Recycling Market Development Zone loan program. Also, in 1994 California established composting regulations that make special provisions for farms, waiving certain permitting requirements if the compost produced is only used on the farm. Such provisions may encourage on-farm composting, although many people in the agricultural community argue that the regulations still are too restrictive.

State universities also have been instrumental in encouraging farm composting. In addition to the university work already mentioned, Michigan State University's dairy manure composting demonstration project has led to a large increase in the number of dairy farms composting in Michigan compared with other states. Pennsylvania State University and the Rodale Institute Research Center cooperatively encourage farm composting, with an emphasis on linking on-farm with off-farm compost feedstocks. In addition, research and demonstration projects by the College of Agricultural Sciences at Pennsylvania State University, in cooperation with the Pennsylvania Department of Agriculture, are emphasizing low-cost methods and machinery selection. Alternative passive aerated-windrow methods are being developed and evaluated for their machinery and labor cost, and for odor and fly control.

Cornell University initiated its farm composting outreach program in 1988 in response to requests from organic farmers, the fruit and vegetable processing industry, and the New York State Department of Agriculture and Markets. Farm composting field days have been offered on over twelve farms throughout the state, and targeted outreach continues. Current efforts focus on the poultry industry, where large composting facilities pose a risk of off-site nuisance odors, and on dairy farms, where composting provides a way to address pathogen concerns, particularly in the New York City reservoir watershed.

Private organizations also have had an impact on farm composting practices. For example, Autrusa CMC Group has coordinated eight seminars in California and Pennsylvania over three years on the Controlled Microbial Composting method, attracting over 200 participants. Most of these participants have become composters and several avidly publicize the benefits of composting within the agricultural community.

Table 1. State cost-share programs for poultry mortality composting (Kashmanian and Rynk, 1996).

State	Cost-Share Rate (%)	Maximum Cost-Share ($)
Alabama	60	3,500/year
Delaware[1]	75	3,500/year
Maryland	87.5	10,000
North Carolina	see note *2*	15,000/year
Ohio[1]	75	7,500/year
Tennessee	75	30,000/year
Virginia	75	7,500/year

[1] Cost-share levels are determined at the county level.
[2] Cost-share amount is based on an average cost per unit for construction of poultry mortality composting unit and storage structure.

Economic Incentive Programs

As expected, cost is a barrier for farms to compost (Kashmanian and Rynk, 1996). For example, since many farmers cannot control the price they charge for their products, they cannot pass along additional costs. Without economic incentives, promoting widespread adoption of composting may be difficult.

Several states, including Alabama, Delaware, Maryland, North Carolina, Ohio, Tennessee, and Virginia, as well as USDA and some poultry companies, provide cost-share funds and other subsidies as an economic incentive for composting poultry mortalities (Table 1). Most farms that currently compost do so to handle poultry mortalities (Kashmanian and Rynk, 1996). The maximum cost covered by these programs ranges from 60% to 87.5%, and from $3,500 to $30,000 per year. Ohio has cost-shared manure composting up to 50% as part of its "NatureWorks" program. This program was initially expected to be funded with $500,000 over six years, with $175,000 for each of the first two years (fiscal 1995 and 1996). However, after the first year's funding, the second year's funding was zeroed out and it is uncertain what will happen during the following four years.

USDA also has a cost-share program for composting livestock mortalities and livestock manure. USDA once had a rule against providing cost-share funds to a poultry mortality composting facility in operation less than five years. However, in 1992 USDA rescinded this rule for states that recently allowed composting as a method to handle mortalities. The maximum cost-share is 75% and $3,500 per year. To emphasize and encourage more composting, in 1994 USDA separated composting from the general category of animal by-product/residual management. In FY 1996, 299 farms from 22 states (Alabama, Arkansas, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Maine, Maryland, Mississippi, Missouri, New York, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Vermont, Virginia, and West Virginia) received USDA cost-share funds for composting, compared with 288 farms in 20 states in FY 1995. Under the recent Farm Bill, USDA's cost-share programs are being consolidated and replaced with the Environmental Quality Incentives Program. One-half of the program's funds will be devoted to livestock operations. Information is not available to determine what type of livestock operations received the cost-share funds and what materials are being composted.

Table 2. Examples of agricultural composting-related projects funded with EPA Section 319 funds (as of July 1996).

Arkansas	poultry mortality composting
Colorado	horse manure composting
	livestock manure composting and use of compost
Delaware	swine mortality composting
Georgia	poultry litter composting and use of compost (two projects)
	poultry litter composting
	poultry manure composting
Hawaii	swine litter composting
Louisiana	seafood by-product composting
Mississippi	poultry mortality composting
New Hampshire	horse manure composting
Nevada	manure composting
North Carolina	poultry mortality composting
Oklahoma	poultry mortality composting
Pennsylvania	use of manure compost
	use of composted mushroom spoils
Texas	dairy manure composting and use of compost
	dairy manure composting and poultry mortality composting and use of compost
	poultry mortality composting and use of compost
	composting by poultry farms
	use of composted poultry manure/used paper
	cropland application of uncomposted and composted yard trim mings
Utah	manure composting

In addition, EPA has funded on-farm composting projects through nonpoint source pollution management grants under Section 319 of the Clean Water Act. Table 2 shows that the interest in composting goes well beyond poultry mortalities.

The seven states identified with cost-share programs vary in how they operate in conjunction with USDA's cost-share program:

- Alabama: USDA's cost-share is applied to the remaining cost after subtracting money received by the farmer from the state's cost-share.
- Delaware: The state's cost-share amount plus USDA's cost-share amount is limited to 75% and $3,500 of the farmer's cost per year.
- Maryland: If the eligible cost is greater than USDA's cost-share contribution, this will determine the state's cost-share amount, within the limits of the state's cost-sharing.
- North Carolina and Virginia: If the eligible cost is greater than USDA's cost-share contribution, this will determine the state's cost-share amount, within the limits of the state's cost-sharing, but the farmer must pay at least 25% of the cost.
- Ohio: The state's cost-share amount cannot exceed $7,500 or, if combined with USDA's cost-share, more than 75% of the farmer's cost.
- Tennessee: The state's cost-share amount plus USDA's cost-share amount cannot pay for more than 90% and $8,500 of the farmer's cost per year.

These states attach various requirements to the award of their cost-share funds, as summarized in Table 3.

There are other state sources of funds, namely low-interest loans for composting poultry mortalities (Alabama, Delaware, and Missouri). Loan amounts range from $2,500 to $10,500 at 5% interest in Alabama, and $1,000 to $60,000 at 3% interest in Delaware. The requirements of these loan programs are summarized in Table 4, with additional information given below:

- In May 1994, the Alabama Agricultural Development Authority announced a joint venture with the Alabama Cooperative Extension Service (through Auburn University), financial lenders, and poultry integrators and farmers to provide a $750,000 loan program to support composting of poultry mortalities.
- Delaware's state revolving fund (SRF) from its water pollution control program (a loan repayment program seeded with federal Clean Water Act funds) can be used to provide loans of $1,000 to $60,000 for units to compost poultry mortalities. Funding can cover up to 100% of the installation costs that are not covered by state or federal cost-share funds and 90% of the installation costs if no cost-share funds are received. This program can be used to finance the construction of NRCS-approved composting units and the purchase of front-end loaders or bucket loader attachments to tractors to facilitate the composting.
- Similar to Delaware's program, Missouri allows the use of SRF money to provide loans for poultry litter and mortality composting. This is a cooperative venture between the Missouri DNR and Department of Agriculture, EPA, the Missouri Clean Water Commission, and the Missouri Agricultural and Small Business Development Authority. If the state DNR and EPA allow it, the state may also include swine mortality composting in this program.

Ohio also has a low-interest loan program, although it is not targeted exclusively to encourage farm composting. The state developed the Water Pollution Control Loan Fund Linked Deposit Program, which targets specific problem watersheds and aims to reduce manure runoff, soil erosion, and other nonpoint source pollution. To satisfy the requirements of the program, a farm must develop a soil and water conservation plan in conjunction with the local soil and water conservation district. Composting may be included as part of this plan. Funds for the program come from the state's SRF, channeled through participating local area banks. The interest rates charged on the loans are up to 3% less than the banks' normal rates, and the period for the loans is no more than 20 years.

Kashmanian and Rynk (1996) provided

Table 3. Requirements of state cost-sharing programs for poultry mortality composting.

State	Installation/ Size/Maintenance of Composting Units	Training of Composters	Permits for Composting Units	Use of Compost
Alabama	Meets NRCS standards and local or state regulations/ According to minimum size needed to solve conservation problem/≥ 10 years	NS[1]	NS	NS
Delaware	Meets NRCS standards/NS/≥ 10 years	NS	NS	NS
Maryland	Meets NRCS standards and specifications/ According to facility's normal flock size and mortality rate/≥ 15 years	Attend composting course taught by University of Maryland	NS	Included in farm's nutrient management plan
North Carolina	Meets NRCS and Cooperative Extension Service standards/NS/≥ 10 years	NS	Issued by state veterinarian	NS
Ohio	Meets terms of state Department of Natural Resources and NRCS standards, and approved by Soil and Water Conservation Districts/ NS/≥ 10 years	Attend composting course taught by Ohio State University Extension Service	Only issued by state EPA if compost is distributed for use off farm	Included in farm's resource management system conservation plan
Tennessee	Meets NRCS standards/ According to facility's normal flock size and mortality rate/≥ 10 years	NS	NS	NS
Virginia	Meets NRCS's specifications and complies with local and state regulations/ According to facility's current normal flock mortalities/≥ 10 years; subject to inspections by Soil and Water Conservation Districts	NS	Issued by state or local government, if appropriate	Nutrient analysis required; nutrient management plan required for on-site use

[1]NS: Not specified.

Table 4. Requirements of state low-interest loan programs for poultry mortality composting.

State	Loan Amount/ Interest Rate/ Pay-Back Period	Maintenance Period for Composting Units	Installation of Composting Units	Use of Compost
Alabama	$2,500-$10,500/ 5%/2 or 4 years[1]	NS; periodic field inspection and educational program by Coop. Extension	According to Coop. Extension certification	Coop. Extension recommends land application at agronomic rate based on N content
Delaware	$1,000-$60,000/ 3%/1-7 years	≥ 10 years; periodic inspection by Soil and Water Conservation Districts	According to NRCS standards and specifications	According to farm's nutrient management plan if loan is to be approved to purchase front-end loader or bucket attachment
Missouri[2]	100% of cost for livestock facility with 1000 animal units/ 5.8 %/< 10 years	No guidelines developed yet	Letter of approval for operation from Missouri Dept. of Natural Resources	Land-applied at agronomic rates based on N content

NS: Not specified.
[1]Two years for mini-composters and four years for other types of composting systems included.
[2]Missouri's program also includes poultry litter composting.

evidence that these economic incentive programs have been effective in encouraging farms to compost poultry mortalities. Based on information collected in 1995, they reported that "almost 60% of the farms permitted to compost mortalities in North Carolina have received cost-share funds from the state. Over one-half of the poultry farms composting in Delmarva have received state and/or USDA cost-share funds. Approximately 600 poultry farmers in Maryland have been taught a composting course by the state university, one of the conditions to receive state cost-share funds. One hundred poultry farmers have signed up for Alabama's loan program, a program that is two years old and became statewide in May 1994. This represents up to 10% of the farms composting poultry mortalities in the state; in addition, nearly 20% of the farms composting mortalities have received state or federal cost-share funds. Approximately 6% of the poultry farms composting mortalities in Delaware have received state loans."

Several vertically integrated poultry companies encourage their growers to compost mortalities. For example, Hudson Foods provides cost-share funds for their poultry farms to compost mortalities in the Delmarva region. Butterball Turkey Company requires new turkey operations in Kansas, Missouri, and Oklahoma to install mortality composting units. To help defray the costs of building a new facility (including manure storage and mortality composting), the company pays a rebate of $1.29 per square foot of space used to raise the turkeys (roughly equivalent to 25% of the total cost of the operation, including the composting unit). The rebate is used to help offset initial construction costs, which may or may not include the composting unit. Other poultry companies may specify in their contracts with their growers, especially the new ones, that they will be prohibited from using incineration or burial pits to handle their mortalities and only allowed to use rendering or composting. In addition, when composting poultry mortalities was a new practice, Perdue Farms gave mini-composters free to its smaller growers in the Delmarva region and provided technical assistance on how to compost. Perdue also strongly encouraged its new growers to compost their mortalities. As composting became widely accepted by its growers, Perdue scaled back its incentives. (As of May 1994, approximately 60% of its growers in the Delmarva region were composting their mortalities). It currently provides thermometers free to growers to measure the temperature in their piles and to help them understand what steps are needed next in the compost process.

Conclusions

Farm composting is expanding, in part because of a variety of incentive programs established by numerous public and private organizations. No single type of program stands out as the best way to encourage farm composting. However, it is reasonable to suggest that a combination of research, education, technical, and economic assistance will help farmers realize the advantages that composting offers in appropriate situations. The successful example of mortality composting in the poultry industry is evidence of this. In addition, the cooperation and partnership of several organizations strengthens the effort and broadens the impact of the incentive programs. If a particular state or regional organization is eager for farm composting to become a common practice, it should implement appropriate technical, regulatory, and economic incentives. Otherwise, the pace at which composting is adopted will likely be slow.

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NEW PLAN BOOSTS CLEAN WATER ISSUES, BUT RAISES QUESTIONS

President Clinton has proposed a Clean Water Action Plan that was perceived as a boost for clean water issues, but consisted primarily of "doing existing programs smarter," according to David Ervin, Director of the Wallace Institute's Policy Studies Program. The President requested an additional $568 million in Fiscal Year 1999 to implement the plan, bringing total expenditures on the package to $2.3 billion over five years.

The plan lists 110 key action steps, including asking for $120 million in new assistance to states and tribes to curb polluted runoff and encourage the adoption of enforceable controls. The most significant actions, according to Ervin, are a commitment to create numeric criteria for nutrients, such as nitrogen and phosphorous, in water bodies by 2000 and initiate standards to enforce them if states do not; and a new strategy to control runoff from cattle, poultry, and pig farms with a goal of issuing discharge permits to the largest farms by 2005.

"These are steps in the right direction," Ervin said. "We hope they will be done sooner, and that the criteria and standards are well set." The plan, however, lacks an aggressive research and technology innovation strategy, and a clear approach for solving transboundary water pollution issues, he said.

BOOK REVIEWS

Agricultural Biotechnology and the Environment: Science, Policy and Social Issues. By Sheldon Krimsky and Roger Wrubel. 1996. University of Illinois Press, Hampden Post Office, PO Box 4856, Baltimore, MD 21211. $47.50, hardcover; $18.95, paper. xiv+294 pp.

This book contains a thorough and even-handed review of agricultural biotechnology product development and its likely environmental impact through 1994, when the manuscript probably went into production. Krimsky and Wrubel explain the agricultural rationale for products such as herbicide tolerant crops, microbial pesticides, and animal growth hormones. They survey alternative scientific strategies for accomplishing these objectives and explain both the mechanisms and the driving logic for addressing them through in vitro manipulation of recombinant DNA. The book includes summary reviews of the literature on the food safety, environmental, and social consequences of various rDNA products, including Calgene's anti-sense tomatoes, Monsanto's Posilac (rBGH), and several Bt crops. Chapters are also devoted to failed projects such as ice-nucleating (or "ice-minus") bacteria and to emerging ideas such as animal bioreactors. The prose is clear and the analysis lucid, and the argument should be accessible to anyone with even minimal training in biology or agriculture.

Most of the book is dedicated to dispassionate reporting on agricultural biotechnology. It will prove invaluable to those who want to learn about how molecular biology has influenced agricultural research and technology development since 1980. The key thesis, argued in a few scant passages, is that agricultural biotechnology has been driven by science rather than by need. According to Krimsky and Wrubel, agricultural biotechnology does not arise in response to scarcity or problems faced by producers, as traditional economic models of scientific innovation would predict. Instead, advances in basic sciences are tailored to the development of technologies that will be adopted because competitive pressures (agricultural economist Willard Cochrane's "technology treadmill") leave farmers little choice. The potential profit for input suppliers provides a rationale for investing money in science, which provides the incentive for more research, but the needs of primary producers and consumers have little impact on the choice of research problems.

Krimsky and Wrubel conclude, "There is nothing intrinsically sustainable or nonsustainable about biotechnology. It represents a set of tools that must be viewed within the political economy of agriculture. In itself, biotechnology cannot be a sustainable process unless it is embedded into a system of sustainable agriculture" (p. 237). Their assessment of progress to date is decidedly negative: "There are no signs of significant change in the refashioning of agriculture toward environmental goals" (p. 252). It would be possible to revise that judgment in light of events since they completed their research (at least to substitute "few" for "no"). A story in *The Economist,* for example, highlights Monsanto CEO Robert Shapiro's commitment to environment (April 26, 1997, p. 66). Yet *Agricultural Biotechnology and the Environment* illustrates well why it will be difficult to break the science-driven mode of biotechnology product development and to make the commitment toward alternative technologies and research strategies.

Paul B. Thompson, Department of Philosophy, Purdue University, West Lafayette, IN 47907-1360.

REPORT CALLS FOR NEW PLANS TO SAVE BT

The Bt toxins, natural pest-control products, are threatened by the development of genetically engineered crops which will make insects resistant to Bt, according to a new report by the Union of Concerned Scientists. "Now or Never: Serious New Plans to Save a Natural Pest Control" recommends ways to strengthen the resistance management plans for the three genetically engineered, or transgenic, Bt crops currently commercialized in the United States. These three crops—corn, cotton, and potato—are genetically engineered to produce Bt toxins.

"Transgenic crops are a threat to Bt because they produce toxin throughout much, if not all, of the plant's life," the report says. "Constant long-term exposure of pest populations to Bt encourages survival of individual pests that are genetically resistant to the toxin. Over many generations, the proportion of resistant individuals in pest populations can increase, reducing the efficacy of the Bt toxin as a pesticide."

Scientifically credible resistance management plans, which consist of measures to delay or prevent resistance, are the key element of any strategy to save Bt, according to the report. The scientists contributing to the UCS report developed plans they say would substantially delay the evolution of resistance to Bt.

"Now or Never" is $14.95 plus $3 shipping/handling from UCS Publications, Department N, Two Brattle Square, Cambridge, MA 02238-9105; (617) 547-5552.

INSTITUTE NEWS

Jill Auburn Becomes Director of SARE Program

Dr. Jill Auburn, a member of the Wallace Institute's Board of Directors, became the director of the USDA's SARE program in January. She had previously been the Associate Director of the Sustainable Agriculture Research and Education Program at the University of California, Davis.

From 1994 to her appointment at SARE, Dr. Auburn worked half-time as the Regional Training Coordinator with the Western Region USDA-SARE program. She also served as Chair of the Sustainable Agriculture Network Management Committee, and was instrumental in launching not only SANET, the communications and outreach arm of the SARE program, but also many other SAN projects from 1991 to 1995.

She joined the Wallace Institute Board in 1996.

Paul Johnson, Retired from USDA, Rejoins Wallace Institute Board

Paul W. Johnson, who served as chief of the USDA's Natural Resources Conservation Service for three years before resigning last year, has been re-elected to the Wallace Institute's Board of Directors. Johnson was an Iowa farmer and former state representative before taking over the agency in 1994, when it was called the Soil Conservation Service. He had been a board member and consultant with the Wallace Institute before he joined the USDA.

Johnson resigned from the USDA in November, saying he wanted to re-establish livestock on his farm, which recently has produced Christmas trees.

Norm Berg Wins NACD Award

The National Association of Conservation Districts has honored Norm Berg, a member of the Wallace Institute's President's Council and the Soil and Water Conservation Society's Washington Representative, as the recipient of the 1998 NACD Distinguished Service Award. This award is presented annually to recognize individuals for outstanding work and leadership in soil and water conservation.

Berg worked at the USDA's Soil Conservation Service from 1943 to 1982, when he retired after a three-year term as chief of the service. He played a key role in many USDA projects, including serving as Chair of the USDA Land Use Executive Committee, leader of the Resource Conservation Act Management group, and member of the Secretary of Agriculture's Coordinating Committee for the Soil and Water Resources Conservation Act.

Since his retirement from the USDA, Berg has been the Washington Representative of the SWCS and the Treasurer of the Natural Resources Council of America.

PROPOSED NATIONAL ORGANIC STANDARDS—FINALLY

The USDA has released proposed rules for organic production which spell out an agency-run accreditation program for state and private organic certification agents, and the first-ever national standards for organically grown food. The proposed rules "take a step in the right direction, but several deal breaker issues remain, and we need to tell USDA how to fix the proposal," according to Kathleen Merrigan, the Wallace Institute's Senior Analyst and a member of the National Organic Standards Board. She praised the USDA for ending its historic opposition to organic agriculture, saying "the willingness of this Administration to embrace organic agriculture indicates real progress. Strict national standards and qualified inspectors will bolster consumer confidence and lead to market growth. The likely outcome is that more farmers will go organic and our soil, water, and wildlife will be better off."

The proposed standards, which took seven years to develop and release, define "organic" as agricultural products produced through a natural versus synthetic process.

The proposal drew criticism from environmentalists and organic farmers who "worried that the rules could permit use of germ-killing irradiation, growth of genetically altered crops, and spreading of sewage sludge as fertilizer," according to the Associated Press. The National Organic Standards Board rejected all three practices, about which the USDA put off a final decision, calling for public comment on them.

According to Merrigan, "Our major concern with the USDA program is the attempt by the Secretary to usurp the role of the National Organic Standards Board in determining which synthetic substances may be used in organic production."

The proposed organic standards rules are available for public comment until May 1. Written comment may be sent to Eileen S. Stommes, Deputy Administrator, Agricultural Marketing Service, USDA, Room 4007-S, Ag Stop 0275, P.O. Box 96456, Washington, D.C. 20090-6456; fax, (202) 690-4632. They can also be sent via the Internet through the National Organic Program home page at http://www.ams.usda.gov/nop, where the rules are posted, and other public comments are available for review.

UPCOMING EVENTS

April 15-17, "Team Wetlands: 101 Ways to Win for Wetlands" will be held in Arlington, VA; contact Terrene Institute, 4 Herbert St., Alexandria, VA 22305; 1-800-726-4853 or (703) 548-5473; e-mail terrinst@aol.com.

April 25-28, "Rally for America's Real Places: Best Practices in Heritage Development and Cultural Tourism" will be held in Chicago, IL; contact National Center for Heritage Development, 5520 Connecticut Ave., NW, Washington, D.C. 20015; information available on the Internet at http://www.nchd.org.

April 27-28, Amish Community Study Tour will be held; contact Ed Martsolf, A Whole New Approach, 1039 Winrock Dr., Morrilton, AR 72110; (501) 727-5659.

May 1 is the deadline for abstract submittals for the 1999 International Erosion Control Association Conference and Trade Show in Nashville, TN, Feb. 22-26; and the Asia-Pacific Conference and Exposition on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, to be held in The Philippines, April 19-21, 1999; contact IECA, P.O. Box 4904, Steamboat Springs, CO 80477-4904; 1-800-455-4322; e-mail ecinfo@ieca.org

May 17-19, National Extension Tourism Conference will be held in Grantville, PA; contact Conference and Short Courses Office, Pennsylvania State University, 306 Ag Admin Building, University Park, PA 16802; (814) 865-8301; e-mail grp1@psu.edu; on the Internet, http://www.cas.psu.edu/docs/casconf/nercrd/NTC/ntc.html

May 22-24, "EarthSpirit Rising" will be held in Cincinnati, OH; contact EarthSpirit Rising, 553 Enright Ave., Cincinnati, OH 45205; (513) 921-5124.

May 27-31, Seventh International Symposium on Society and Resource Management will be held in Columbia, MO; contact Dr. Sandy Rikoon, ISSRM Co-Chair, University of Missouri-Columbia, Rural Sociology, Sociology Building 108, Columbia, MO 65211; (573) 882-0861; e-mail ssrsjsr@muccmail.missouri.edu; on the Internet, http://www.ssu.missouri.edu/ssu/issrm

May 31-June 5, "Ethics and the Culture of Development: Building the Sustainable Economy" will be held in Havana, Cuba; contact American Friends Service Committee, Latin America and Caribbean Programs, 1501 Cherry St., Philadelphia, PA 19102; (215) 241-7159; e-mail idlac@afsc.org; on the Internet, http://www.afsc.org/cubahome.htm

June 3-6, "Who Owns America? How Land and Natural Resources Are Owned and Controlled" will be held in Madison, WI; contact Lynn Meinholz or Robin Gigot, North American Program, Land Tenure Center, 1357 University Ave., Madison, WI 53715; e-mail ltcnap@facstaff.wisc.edu; on the Internet, http://ltcweb.ltc.wisc.edu/nap

RESOURCES

"Produce Handling for Direct Marketing" ($10.50) and **"Farming Alternatives: A Guide to Evaluating the Feasibility of New Farm-Based Enterprises"** ($11.50) are available from Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Ithaca, N.Y. 14853; (607) 255-7654; e-mail nraes@cornell.edu

University of California Statewide IPM Project Annual Report is available from the Project, University of California, One Shields Ave., Davis, CA 95616; e-mail ipmig@ucdavis.edu

"Walnut Production Manual," 317 pages, is $35 from University of California, DANR Communication Services, 6701 San Pablo Ave., Oakland, CA 94608; 1-800-994-8849.

"1998 Directory of Flower & Herb Buyers" is $10 from Prairie Oak Seeds, P.O. Box 382, Maryville, MO 64468; (816) 582-4084.

"Wisconsin Farmers' Views on Livestock Expansion" is available from the Program on Agricultural Tech. Studies, 1450 Linden Dr., #146, UW-Madison, WI 53705; (608) 265-2908.

"The Economic Merit of Animal Manures as a Source of Plant Nutrients or Energy Generation" is $13 from UC Agricultural Issues Center, University of California, Davis, CA 95616; (530) 752-2320.

"Public Programs for Private Forestry: A Reader on Programs and Options" is $20 from American Forests, 1-800-368-5748; findings are available on the Internet at http://www.amfor.org

"Time for a Change: Pesticides and Wine Grapes in Sonoma and Napa Counties, California" is $5 plus $2 shipping from Californians for Alternatives to Toxics, P.O. Box 1195, Arcata, CA 95518; (707) 822-8497; e-mail cats@igc.org

"Urban Agriculture: An Abbreviated List of References and Resource Guide" is available from Alternative Farming Systems Information Center, National Agricultural Library, ARS, USDA, 10301 Baltimore Ave., #304, Beltsville, MD 20705; (301) 504-6559; or on the Internet at http://www.nal.usda.gov/afsic

"The Future Agenda for Organic Trade," proceedings of the 1997 Organic Trade Conference, are $30 from IFOAM, fax +49-6853-30110, or e-mail ifoam@T-Online.de

"Sustaining Profits and Forests" is $10 from Island Press, Box 7, Dept. 2AU, Covelo, CA 95428; 1-800-828-1302; e-mail ipwest@igc.apc.org; on the Internet, http://www.islandpress.org

Four films: "An Introduction to Ecological Economics" ($25); **"Investing in Natural Capital"** ($29.95); **"Conversation for a Sustainable Society"** ($25); and **"Costa Rica Counts the Future"** ($39.95) are available from Grieslinger Films, 7300 Old Mill Road, Gates Mills, OH 44040; 1-800-872-4456; e-mail Prgfilms@ix.netcom.com

Guide for Authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multidisciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of the authors; 3) affiliation and office address of authors, and 4) disclaimers and publication number, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single-discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key Words

Provide subject matter key words suitable for use in scientific indexing.

Reference List

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized.

Citing References

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript Preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Every figure and table should be mentioned at least once in the text.

A detailed guide to formatting is available from the editor (address below).

Submission of Manuscripts

Submit four high-quality copies to Dr. Robert I. Papendick, Editor, American Journal of Alternative Agriculture, Department of Crop & Soil Science, 253 Johnson Hall, Washington State University, Pullman, WA 99164-6420. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form, that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of family farms and rural communities.

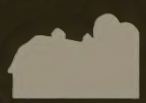
Alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, enhanced environmental quality, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Henry A. Wallace Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

The Wallace Institute also provides these services:

- *A resource to lawmakers and others who influence agricultural research, education, and information policy*
- *A voice for alternative agriculture in Washington*
- *A sponsor of research and education outreach programs*
- *A national clearinghouse for information on alternative agriculture*
- *A publisher of reliable scientific information on agricultural sustainability*

If you're interested in helping us, please contact the Henry A. Wallace Institute for Alternative Agriculture, 9200 Edmonston Road, Suite 117, Greenbelt, Maryland 20770-1551. Telephone: 301-441-8777; E-mail: hawiaa@access.digex.net; Web site: www.hawiaa.org



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